THE MODELLING OF FACTORS INFLUENCING OBSERVED MANPOWER PRODUCTIVE TIME WITHIN THE SITE PRODUCTION PROCESS

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LIST OF ABBREVIATIONS

BRE	Building Research Establishment
BRESAAP	Building Research Establishment Site Activity Analysis Package
CLR	Classical Linear Regression
CCPWP	Comparative Construction Performance Working Party
DBMS	Database Management System
F	Fahrenheit
FDS	Foremen Delay Survey
GLM	Generalized Linear Modelling
GNP	Gross National Product
GPR	Generalized Partial Residual
LUF	Labour Utilization Factor
MRC	Management Related Categories
NECA	National Electrical Contractor's Association
NEDO	National Economic Development Office
NP	Number of Observations Productive
NT	Total Number of Observations
OMR	Optical Mark Reader
THM	Theoretical Model
UK	United Kingdom
USA	United States of America

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ABSTRACT

Productive time utilization is low and varies considerably. This study attempts to make a quantitative examination of the more influential factors through on-site observations and subsequent analysis.

The investigation using a modified form of activity sampling, which yields information on many factors, was undertaken on one site throughout its construction. Subsequently, data was processed and transformed using database concepts and analysed by the 'Generalized Linear Modelling' technique.

The results suggest that fewer factors than previously postulated are needed to explain the variations. Quantitative factors that were statistically significant, given the data obtained were: task variability; task significance; task duration; task interruption; management team; interruptions due to design/quality; task interdependence; trade variability; trade duration; trade significance and bad weather. There is also evidence to suggest that rationalized design elements; superstructure and services elements; trades within the control of the main contractor; production at ground level, have low productive time relative to their counterparts.

The findings were constrained by the limitation imposed by the data collection system and its processing capabilities which cannot accommodate more factors. Future work should consider the use a new database processing

system as well as the use additional methods of data collection. Nevertheless, the variations that can be explained reinforced the current understanding that the nature of construction work is subject to considerable variation.

The need for a comprehensive method of assessment of manpower time utilization and subsequent rigorous substantiation of the surrounding events have been highlighted. The findings should provide more empirically established evedince for the field of study. The importance of productive time measurement and the diagnosis of potential problems have also been emphasized.

INTRODUCTION

INTRODUCTION

The continuing decline of construction productivity at the macro level is coupled with evidence that productivity achievement at the site level is also low. One of the factors contributing to this decline is the low utilization of resources at the site level. Productive time measurement is a measure of utilization of resources which is becoming more popular as a productivity indicator. There is substantial evidence for the hypothesis that productive time achievement is always low and that considerable variations exist on most sites.

This study is aimed at ascertaining the more influential factors causing the variations in productive time. Productive time measurement originated in manufacturing industry as a techniques of work study. The application of work study techniques to production processes at the site level is, however, constrained by many difficulties. The main problem identified in this research is that productive time measurement cannot be easily appplied as part of the work study procedure. This is because once a proportion of low productive time has been identified for a particular piece of work, that work may well already have been discontinued. Thus to improve the productivity of the operation, the same piece of work has to be examined on another site and using other techniques of work study. This give rise to further problems of differing project and site characteristics, which may again invalidate any findings.

Productive time measurement during on-site production will be more useful, if its influencing factors can be easily determined. The identification of significant factors influencing productive time will give an indication of the possible factors influencing labour productivity, as well as problems in manpower resource utilization. The strategy is to examine productive time in terms of its attributes and the attributes of the production process. Periodical data on productive time, the classification of manpower and the production classification output are thus the attributes from which productive time can be examined.

For all of these a form of database is required, such that productive time data can be extracted, transformed into its attributes and retrieved. The Building Research Site Activity Analysis Package (BRESAAP) was examined and was found to exhibit some of the characteristics of a suitable database. BRESAAP accepts data input which when transformed will give information relating to various aspects of factors influencing productive time. However, further work is necessary as the transformation process is not available in BRESAAP.

The current concept of productive time is fragmented mainly because of the failure satisfactorily to adopt it as a work measurement technique. Three problem areas were identified for critical examination:-

i. The conceptual framework of productive time measurement is based on classical theory that its measurement indicates efficiency of management. Thus it needs to be re-defined for use as a productivity indicator.

ii. Since the conceptual framework is seldom defined and is based on the classical theory, the quantitative measurement of variables has not been achieved: Subjective analysis is thus the more common method of analysis found in the literature.

iii. If the aim of ascertaining the factors influencing the productive time is to be achieved, the conceptual framework and the data collection have to be made to suit the capability of a particular method of analysis.

The research therefore examined these problems in detail and proposed to solve the problem of determining the factors influencing the productive time through:-

i. The formulation of a conceptual framework to define the relationship between productive time and its influencing factors.

ii. The adoption of a data collection mechanism which will measure productive time and its influencing factors and provide a database for analysis.

iii. The application of Generalized Linear Modelling Technique (GLM) to achieve the objective of identifying the significant factors influencing productive time and to help in the derivation of the conclusion for this research.

Productive time within the production process is presented in this thesis as composed of various attributes. Five attributes were included in the framework: the weekly, trade, element, operations and gang - all defined specifically in the context of this research. The theoretical argument is that productive time has to be examined from many levels because the concept has hitherto been too generalized and because the influence of various factors at different levels will be different. Hence the examination of factors without prior consideration of this aspect may be misleading.

The data input to the database adopted the BRESAAP method of data collection. The study was undertaken for approximately 80 weeks on the actual construction of an educational building project. The data was then processed and the output abstracted, in accordance with the conceptual framework, ready for analysis by GLM.

Productive time has customarily been expressed as a percentage. The use of percentage figures to indicate the extent of productive time achievement is misleading for this study principally because the actual productive time of different cases will be different. The use of percentages to generalize a given situation does not take into account the influence of those differences. The analysis will thus yield an inaccurate picture of the influential factors.

The use of GLM enabled, first, the analysis of multiple significant factors and was thus likely to provide the best set or sets of influencing factors for a particular level of productive time. Secondly, GLM is required because the data collection principle is based on the binomial theorem. The assumption that the data will be approximately normal using the central limit theorem will not be valid in all cases of data arising from site production. With GLM, analysis can be made without the normality assumptions and testing. Thus the GLM is a powerful and flexible tool in data analysis. Data from the exponential family of distribution which is not always normally distributed, can now be easily analysed without the normality assumptions having to be fulfilled.

CHAPTER ONE

CHAPTER ONE

1 VARIATION AND LOW PRODUCTIVE TIME ON CONSTRUCTION SITES

1.1 CONSTRUCTION PRODUCTIVITY DECLINE

Investigations into construction productivity measurements and efforts to ascertain the factors influencing construction productivity have attracted increasing attention since the late 1970's. There is an increasing number of new approaches aspiring to untangle the mystery of construction productivity. Most of these efforts are yet to be coordinated. A closer examination of some of the statistical evidence may yield some answers.

The rate of growth of construction productivity in the United States of America (USA) has been reported to be around 1 percent immediately after the second world war and rising to between 2 and 2.5 percent during the post war period (1). Between 1950 and 1968, it rose anually by 2.4 percent. However, between 1968 and 1978, it declined by 2.8 percent (2) and this decline continued up to 1983 (3). The rate of the decline reported in the most recent study covering roughly the same period is estimated to be around 20 percent (4).

The overall productivity and economic indicator of the United Kingdom (UK) showed, it dropping from the second to the twentieth place among the leading industrial nations in the 26 years from 1953 to 1979 (5). In the UK construction industry, the average labour productivity showed a similar trend to that of the USA, with a steady growth in the 1950's and 1960's and declining in the 1970's (6). Overall UK industrial productivity and its construction industry productivity may perhaps have increased during the period of Conservative government (1979 to 1988), but no evidence can be found to substantiate this supposition in the case of the construction industry.

Comparisons of the rate of growth of construction productivity in Europe and the USA indicate that it is 3 to 7 times faster in Europe than in the USA (1). In addition, the rate of growth of construction productivity is slower than that of other industries (6). Within the construction industry itself, the rate of decline in the power and industrial construction sector is faster than the rest of the construction industry (4).

The abundance of statistical evidence pointing to a continuing decline in construction productivity may perhaps have been the reason of increasing interest in research in construction productivity. The trend of the decline is most evident at the macro level and most of the published reviews have referred to indicators at this level. There are, however, problems in the use of broad productivity indicators and in their interpretation. In the most comprehensive review to date of the system of measurement, it was found that the existing system of measurement is inadequate (7). No single measurement is sufficient for the industry and a series of productivity indices are needed for different purposes. Even taking into account the problems in the use, interpretation and insufficiency of the indicators, there must be serious concern at the continuing decline, which is leading to conferences and symposia on construction productivity (8). These efforts are still largely uncoordinated. This study is not however aimed at examining these problems in particular.

The decline at the macro level may be due to low productivity achievement at the site level. Fox (9) indicates that 15 to 40 percent of the construction cost in the USA is estimated to be lost due to low productivity. The fundamental cause of the continuing decline at the macro level could lie in low productivity achievement at the site level. No consistent and reliable data on site level productivity are available. Such an assumption will thus be difficult to justify, but there is clearly a very strong link between the two. The presumption can be backed-up if productivity is viewed as a system. Thomas et al. (32), noted that if a problem exists at the upper level of a certain system, the tracing of the problem will lead to the source of the problem. The source is the lower level attribute in a particular system. The site level productivity is the low level attribute of the construction productivity system (11). Thus, there is a need to examine more closely the causes of low productivity achievement at the site level. Published reports on site level productivity are based on a single piece of study undertaken at a particular time. Based on the aggregation of the evidence from these types of study, productivity achievement at the site level and its influencing factors can be examined.

1.2 LOW PRODUCTIVITY DUE TO INEFFICIENT TIME UTILIZATION

The impact of low productivity on Gross National Product (GNP) and the quality of working life at the macro level and at the micro level, its consequence for cost, profit margin, pricing, competitiveness and to some extent survival of an organization, is a central thesis in many discussions. Low productivity is a problem to all concerned in the construction industry. It is both a management and engineering problem (12). There are many reasons why productivity at the site level could be low.

There is evidence to suggest that one of the main reasons is the low effective utilization of manpower resources (13). A National Economic Development Office (NEDO) report (14) emphasized that a fundamental factor clearly associated with lower than average productivity, as found in a study on UK sites undertaken for the Comparative Construction Performance Working Party (CCPWP), was the low proportion of time engaged in actual construction. This implies that productive time is a factor of productivity. As the percentage of productive time reduces, there will be greater need for additional resources through increased manpower requirements, implying an increase in the input to the production process (15). The alternative is to slow down the work (16), which will delay the project with further negative consequences. As the cost of manpower is about 25 to 40 percent of construction cost (17), any inefficiency in manpower utilization will contribute significantly to the site level productivity. Tucker (18) suggested that only about 20 percent of theoretical work hours are actually used in putting work in place. If this suggestion is correct, then the rippling effect to site level productivity and consequently to macro level productivity, must be disastrous.

Improvement in labour productivity at the site level can be achieved through efficient utilization of the labour resource. One of the ways to ensure efficient utilization is through effective utilization of time.

1.3 MANPOWER TIME UTILIZATION

Manpower utilization of time is made up of various components of activities. To ease discussion and understanding, and, most importantly, to ease onsite measurement, these activities are coded in various forms to represent the main activities undertaken by manpower. Classification will depend on the purpose of the exercise and the purpose of the information collected. Most classifications differ substantially, making comparison difficult. Generally, time utilization is classified into productive time (direct work), indirect productive time (support work) or unproductive time. Time utilization gives a numerical value to the way time is utilized. Time utilization can also be classified in other ways. BS 3138 (19) classified time utilization for work performance control. The BRESAAP classification (20) allows for further subdivision of activities in the indirect and unproductive time category. Cale (21) and the British Institute of Management (22) described a form of time utilization classification for use also in activity sampling. Thomas (23) also described the many ways time utilized can be classified.

1.3.1 PRODUCTIVE TIME ACHIEVEMENT

Separate but extensive site studies have been reported from time to time on the measurement of manpower time utilization at the site level. These studies were undertaken for different purposes.

A general inter-site comparison revealed a disturbingly low output of productive time on various sites. Aird (24) reported that in his study an average worker was productive for only 55 percent of his time, the remaining 45 percent was spent in an unproductive and indirectly productive manner. Housing studies in the United Kingdom (UK) in the late 70's and the early 80's also showed the same trend. A percentage of 53 percent in Blantyre (25), 41 percent in Greenfield (26), 43 percent in Pitcoudie 1 (27) and 48 percent in Pitcoudie 2 (28) were recorded for productive time proportion in these studies. Studies conducted in the United States of America (USA) reported an average of about 30 percent for productive time proportion (29,30,31). Figures published by Thomas et al. (10, 32 and 33) also recorded extremely low productive time proportion especially at the crew level. Two studies which yield higher productive time were, however, reported by Griffith (34) and Forbes (35). Freeman (36) noted that Forbes's result is unusual and seldom achieved. Baxendale (37), in reporting three case studies, noted that the total productive and indirect productive time in his work varied from 37 to 71 percent with a mean of 51 percent.

In a more general study of eleven sites in the UK, Europe and the USA undertaken by the CCPWP on Engineering Construction Performance (14) the same trend was evident. Although the studies actually measured activities defined as construction work, which is a broader definition of productive time, a range of only 14-55 percent of paid time can be apportioned to activities relating to construction work. Sufficient evidence therefore exists, to suggest that productive time utilization at site level is usually low, perhaps averaging only about 50 percent (38).

Considerable low time utilization is liable to a number of negative interpretations. It indicates that manpower productive time at site level is generally low, manifesting an ineffective time utilization. A few conjectures can be formed when the above evidence is taken in conjuction with the NEDO reports on Value For Money To Client (39) and on Faster Building For Industry (40) serving to strengthen the reasons for undertaking the research:-

i. The client is not getting value for money in terms of optimum time utilization of workforce at the site level. Payment is being made at inflated prices, since the contractor's pricing may already have taken into account the ineffective time utilization effect.

ii. Extra manpower at the site level will be needed which can create industrial relations problem as noted by Callahan (15), demanding efficient site management, increasing basic labour cost, and reducing profit margin to the contractor as well as increasing prices to clients.

iii. Construction periods can be prolonged because more time is needed to complete a task, resulting in a lengthier construction time as indicated by the NEDO reports.

These broader issues of better value for money, faster building, improved industrial relations and increased profit margins could be related to low productive time utilization at the site level. It is not easily proven, but there is an indication from the literature that it could be one of the factors influencing the broader issues, especially in construction industry in the UK.

1.3.2 HIGH VARIATION IN PRODUCTIVE TIME ACHIEVEMENT

Variation in productivity is a norm in the construction industry. Although classical texts of network analysis propose that the variations in activity (defined as construction activity and not activity of time utilization) durations are only occasional (41), the existence of high variation in productive time and productivity is reflected in the literature. The NEDO reports (42,43) indicated considerable variation in productivity which supported Bishop's (16) statement on the existence of large variation in housebuilding time requirements two decades ago. Bishop noted that a small variation in manning rate and tempo of work (+/- 10 percent) would increase man-hour requirement to the range of 1.5:1. There is also a considerable variation in man-hour requirements for housebuilding, with a coefficient of variation of 5 percent expected for houses within a site, 10 percent for houses on different sites by the same firm, and 21.5 percent for different houses by different firms. Further, there is an indication that repetitive operations are subject to variability of about 3:1 (44,45,46). This has led to the conclusion that productivity variability of construction operations is pervasive and large (47). Bennet et al (48) classified productivity variability as a component of uncertainty in construction work. Construction work is thus essentially dominated by the uncertain environment in which it takes place in addition to the wide variety of task types.

The general comparison of productive time achievement revealed that not only is it low, but also that a high variability also exists, even though the data is already expressed in percentages. The larger variation in productive time could result in a proportionate variation in productivity.

Detailed comparisons of tasks, operations and crew productive time from the studies reported above are not possible because of the different nature of the study methods, objectives and classification systems used. What is clear is that the general hypothesis of high variability in most aspects of construction work applies equally well in reference to productive time. What are the causes of the high variation? If the variation can be explained, then steps can be taken to overcome the problem and thus increase productive time. The difficulty in interpreting the large variation is due to the over-reliance on subjective interpretation of the data.

1.3.3 THE CAUSES OF LOW PRODUCTIVE TIME

It is generally understood and accepted that time utilization will not always be productive and thus a hundred percent productive time achievement will not be achieved except in certain specific circumstances. In fact, the proposition is incongruous with the capability of human nature since early study of man at work, originating from Taylor (49), also suggest that short rest periods are essential in physical work. That rest periods are, however, always abused is indicated in a NEDO report (14). The report concluded that good organization of work needs effective management, which is essential to overcome the problem of abused rest periods and low effective time utilization.

Abused rest periods is not the only reason for low productive time utilization and high variation. Conclusions derived from site studies reviewed above suggest that half of the unproductive time may be due to the nature of work and the other half a result of managerial-related factors associated with lack of planning, scheduling, communication, supervision and management training (24). This is also supported by an investigation, using work study methodology (52,53), which indicated that factors affecting site efficiency were the delays caused by poor management, excessive breaks and poor motivation, accounting for half the available working time.

The managerial-related factors are of interest because it has to be accepted that variation in productive time and the considerable low achievement has to be attributed to the nature of work. Supervision, for example, has been found to reduce the normal large measure of inactivity on sites (50). Delays causes by administrative problems and poor work methods have also been suggested to be the causes of low productive time (51). The administrative delays are due to lack of materials, tools, inappropriate equipment, repeat work, crew interference and overcrowded work areas. The reduction in the administratively caused delays can be achieved by monitoring the efficiency of support operations and using the results to encourage improvements in the provision of tools, by promoting better planning and coordination by better craft level planning and coordination. Improvement in work methods for specific activities is best made at crew level where an essential element is the participative decision making of the crew. The study on nuclear power plant construction in USA (29-30) found that the causes of time lost due to delays were, in descending order of importance, material availability (17%), overcrowded working conditions (14%), tool availability (11%), interferences between crews(9%), postponement relating to quality control (6%), receiving instructions (5%).

Further evidence on the influence of managerial-related factors came from Griffith (34,54,55) who found marked differences in the factors which suggest the significant influence of managerial-related factors on productive time utilization against the hypothesized influence of the design or buildability factor (56). Baxendale (37) found the reasons for low productive time in his study to include other factors in addition those which are managerial- related. These factors include inadequate supervision, non-delivery of materials, travel for material, overmanning, imbalance of gang, early quit, poor time keeping, social interaction between operatives and bad weather. The latter two factors can be attributed respectively to operatives and external factors.

Thus there is also evidence to suggest that, apart from the nature of work, managerial, operative and external related factors are also responsible for low productive time achievement. Adrian (57), sumarising the cause of unproductive time, suggested the attribution of the causes of unproductive time to management, industry and labour related factors in equal proportion.

The most important aspect of any study is how the findings of the studies reported above were established. In this respect the literature quoted above can be divided into several categories. First is the literature which reviewed the area as a matter of interest, offering some thoughts but using data and evidence from other studies. In the second category are analytical studies which did not publish the methodology of analysis making it impossible to follow the considerations in the derivation of the conclusion and raising doubts as to the validity of the conclusion reached. Thirdly, there are studies that sufficiently describe how the analysis was made. The third category will be discussed below, including the literature which provides some thoughts on how the analysis should have been done.

1.3.4 CURRENT METHODS OF ANALYSIS

The main problem with data analysis of time utilization is the interpretation of results. The results may give an indication of the extent of time utilization but do not give a clear indication of the causes of such achievement and variability. Basically, data relating to time utilization measurement are derived through the use of activity sampling techniques. To determine the fluctuations in the productive time, the two most commonly used methods suggested in textbooks are the labour utilization factor (LUF), and the control chart.

The concept of LUF makes use of activity sampling data to measure the quality of supervision of foreman, general foreman, supervisors and managers (management force) and not the quality of work of workmen (32). The LUF formulae may or may not make use of the indirect work category (58). LUF offers only numerical measurement and does not attempt analysis of causes. Judgement and experience on the part of the reviewer is needed (32), since acceptable values vary with type of work or craft. Thus, time utilized may be acceptable to one reviewer in terms of quality of management and unacceptable to another.

The origin of the LUF concept is unclear but is thought to arise from the work study concept. Its use as a measure of the quality of management must compare like with like, i.e. one crew of general labourers with another and not with crews of different trades. This is because the percentage of time utilized on various activity will vary with the nature of their tasks. When comparison is made using utilized time to reflect the quality of management, it must be remembered that the figure achieved may not be the only reflection of the quality of management. Parker et al (58) and Thomas (32), noted that LUF cannot reflect the quality of the manpower. This is not entirely the case, since manpower have some influence over its time. To some extent, therefore, it must also reflect the quality of the manpower resource. The findings of the studies quoted above confirmed that the productive time of manpower is also influenced by other factors.

The factor of 1/4 of indirect category work, used in the first formula of the LUF, can also be questioned. Firstly, does it mean that about 75% of indirect work utilized will always be wasteful? This is an arbitrary figure, but is 75% justified? The variation of LUF between trades, as observed by Parker et al. (58) would suggest that the indirect work proportion should vary, though the extent of the variation cannot be easily determined. Whether or not a certain utilization in the indirect work category is wasted must rather be better explained by the use of statistical techniques as well as subjective interpretation which may help to justify the quality of management.

Heiland et al. (59) proposed the use of the control chart when undertaking a study so that the productive time over and below the control limit can then be investigated. The use of the chart could be useful for monitoring purposes but the data must be longitudinal or periodic in nature. Thomas (10) also investigated the use of daily productive time and the moving averages of productive time and found that the moving averages are more useful to track the possible problem in manpower utilization. The techniques of control chart and moving averages are useful as an aid to better judgement or to help identify possible problems, if and when they occur. However, these techniques do not identify what is the probable problem area.

Therefore, LUF, the control chart and moving averages all lack the ability to explain why such variabilities exist, although they are good for detecting the possible problems. Their use as research instruments for this purpose is therefore limited and other methods will be needed for validating the problems which may exist in manpower time utilization.

Most of the studies quoted above rely heavily on subjective interpretation of data in the absence of reliable methods of analysis. The approach is to look for unusual trends in the data (10) or the use of the targeted achievement or what is considered normal (60). Both of these methods obviously require a considerable amount of judgement on the part of the reviewer (32). Normality assumption in the level of productive time is thus used to determine unusual trend or achievement below traget. Verschuren (60), suggested that if unproductive time is avoided, a figure of 79-11-10 for direct, indirect and relaxation categories could be achieved for sites with good organization and time distribution. However, three points need to be noted:-

i. The unproductive time seems to be of less importance in the context of Verschuren's statement, whereas the studies reviewed and figures presented by Verschuren show high percentages of unproductive time. The assumption that unproductive time cannot be totally eliminated is acceptable, but this expenditure has to be justified and controlled.

ii. Verschuren's figure is acceptable if it is a target for management to achieve. When the results prove otherwise, the attribution of responsibility cannot be made directly to bad organization or management.

iii. Normality assumption is relative. Verschuren's figures appear to be too high. Only Griffith's and Forbes' data have so far provided the evidence that this level could perhaps be achieved. Even then, further validation of their data is necessary.

The studies reviewed in section 1.3.4 use other approaches to reach their conclusions. Aird (24) interprets the data by considering each activity classification from the nature of the particular activity. It was difficult to evaluate his method because after considering the nature of a particular activity, he did not describe in detail how he used his considerations to arrive at his conclusion. Griffith (34) analysed the cause of higher productive time utilization in his study by comparing the managerial factors on his site with the other housing studies in the UK. His method of analysis is useful but is directed at inter-site comparisons. Further validation of his findings may be desirable but there is a difficulty in obtaining more inter-site data with the relevant information. The identifications of the factors in his study will be useful. Had he made use of some statistical testing, the argument in the conclusion would be more convincing. Garner et al (29) and Sebastian et al (30) derived their conclusions from a carefully designed experiment, and for the first time provide an empirical indication of the extent of the influence of factors influencing delay at the site level. They used various techniques of data collection including Foreman Delay Survey Technique (FDS). Their method, therefore, does not depend on activity sampling, but the causes influencing delay are analysed from feedback of participants.

Thomas (32), perhaps in an attempt to solve the problems of analysis of time utilization data, suggested how problems with crew performance can be identified by the use of management related categories (MRC) and activity sampling categories. Comparisons were made among five crews and Thomas showed that the problems which may have been identified in the activity sampling data may differ if analysis is made using management related categories. By analysing the data using the MRC, Thomas had combined the activity sampling categories of both the indirect and ineffective work. The categories used by Thomas emphasized more on the analysis of a particular task or crew, with the number of categories of activity sampling being kept in the range of 15 items (59), the recommended number for use in any sampling studies. One of the problems that could arise if this technique were to be used in this research is the way in which the activity categories can be combined. Thus, the main drawback for this technique would be the principle for the assumption of which activity or a group of activities could be associated with a particular problem, such as delay. Furthermore, the comparative analysis problem is again faced: the MRC figure will have to be unusually high or low to reflect the MRC problems. If comparison does not yield any trend, inferences would be difficult to make.

Baldwin (61) proposed that the activity sampling data be collected as part of a designed experiment with a hypothetical model. He recommended that experiments are designed with a specific purpose and that activity sampling be used as one of the tools. While his proposal does not illustrate much on the actual technique of using activity sampling data, the use of a hypothetical model may be a good idea to adopt.

Thus the current methods of analysis of time utilization data cannot be used for this research because most rely heavily either on normality assumption, doubtful principle of attribution of factors or, perhaps, over-reliance on what can be interpreted by many activities of manpower during production. All of these factors taken together form an integral part of subjective analysis, which utlimately will demand the power of subjective interpretation from unstructured data on the part of the researcher. There must be an alternative and better approach in which an investigation into the causes of variation and low productive time achievement can be undertaken.

1.4 RESEARCH OBJECTIVE

The studies reviewed provide all forms of time utilization. Knowing the extent of time utilization is insufficient. The data on time utilization only explain 'HOW' time has been utilized and not 'WHY' such an achievement was recorded. Nevertheless, the logical way to understand manpower utilization is to know how in the first place time is spent, then find out why such a time utilization pattern occurs, before reaching any conclusion on the effectiveness or otherwise of manpower utilization.

There are many causes of low productive time achievement and the high variability which exists. The review of the literature shows the most common factors are the management, design, manpower and external factors. These factors are, however, too general and can be derived in most studies. Within the spheres of management, for example, there are many more specific factors such as supervision, planning, control and monitoring which can cause problems. The identification of which aspects of management are responsible for the achievement of productive time is necessary. The same applies to the other common factors of manpower, design and external factors.

The MAIN OBJECTIVE of this study is therefore to carry out an investigation to pinpoint the factors associated with the main sphere of factors which influence the level of productive time achieved within the production process at the site level. It is the first step in understanding the variables that affect manpower productive time within the site production process, in what way they affect productive time and the significance of these variables. This will assist managers in the management of the production process on site. However, there are problems to be solved before this objective can be achieved. So the first task must be to establish the problems in more definable terms.

1.5 RESEARCH PROBLEMS

The problems in the examination of factors influencing productive time utilization within the site production process can be broken down into three main areas.

1.5.1 METHOD OF ANALYSIS

The current state of the art in the method of analysis of time utilization still depends heavily on subjective judgement. Subjective judgement will always form an important aspect in research analysis, but too much dependancy will require excessive time and effort in analysis. In addition, information which can support the analysis needs to be collated and structured so that the retrieval process can be effective. Subjective analysis will demand that the researcher can comprehend the data and make plausible conclusions and this may leave little time to provide justification of the conclusions reached. Even the most experienced person in a particular field may still find this a very taxing process.

Thomas (32) emphasized that in his experience managers are reluctant to embark on improvement programs if substantive findings are not forthcoming. He further reiterated that analysis methodology of time utilization using activity sampling relies heavily on the judgement, ingenuity and intelligence of the reviewer. There is clearly a need to be able to ascertain the causes of productive time achievement in a quantitative manner and thus reducing the dependancy on qualitative interpretation. To increase the level of productive time, the causes that inhibit or induce it must be known and the improvements must be directed at reducing, eliminating or increasing the magnitude of the factors involved.

1.5.2 RESEARCH FRAMEWORK

It has been noted that while much research work relies heavily on hypothesis testing through formulation of a conceptual framework based on background theory, this is evidently non-existent in the literature reviewed. Although productive time has been the subject of much discussion with the development of method study and work measurement, few research have questioned whether the development of these methods and measures can apply equally well in the production process at the site level. The use of indices can only show a trend, but much of what is revealed from the trend is perhaps only an indication of the severity of the problem. Who can be sure that the low productive time is an indication of inefficient management alone and that no other factors are of significance?

The paramount need is to develope a suitable framework for this research. There is more that could be done in this area, as is evident from the scanty literature. The productive time at the site level is related to manpower utilization, productivity and work study. It is necessary therefore to review the general area of productivity and work study to establish the relationship between work study, productivity and productive time so that the formulation of the research framework can be based on proper background theory.

1.5.3 MEASUREMENT OF FACTORS

The studies reviewed above suggest that management-related factors are responsible for the low productive time in addition to other major factors. This needs further substantiative findings, but the evidence presented may serve to strengthen the hypothesis. Most of the empirical studies have neither included nor discounted the influence of other main factors. What is now necessary is the inclusion of as many variables as possible. These can then be analysed to identify the significant and insignificant factors. Garner et al. (29) and Sebastian et al. (30), despite the careful design of their work have neither considered the external factors and nor discounted the significance of the other factors measured. The problems of determining exactly which factor in a particular circumstance influenced the productive time utilization in a greater magnitude than the rest of the factors can be attributed to the methodology of analysis, but the gaps which exist in knowledge of real life scenario also must be taken into account.

These three problems will need further examination before the actual research can progress and can be summarized as the conceptual and the methodological problem. Chapters 2 and 3 will examine some of the conceptual problems relating to manpower utilization and productive time measurement. Chapters 4 and 5 will examine the potential of the systems and database approach to achieve the objective and thus proposing the methodology for this research. Chapter 6 will hypothesize and determine the influence of factors within the broad sphere of management, manpower, site and external sub-systems conceptualized as within the site production system. Chapter 7 will describe the site observational studies where initial raw data were collected. Chapter 8 will desribe the processing, transformation and retrieval of the raw data into observed productive time data and the transformed variables. Chapter 9 will model the influence of variables to the data. Chapter 10 will discuss, draw implications and evaluate the methodology used. Chapter 11 will summarized the findings and make recommendations.

CHAPTER TWO

CHAPTER TWO

2 MANPOWER RESOURCE AT THE SITE LEVEL

2.1 OVERVIEW

The problem identified in chapter 1 necessitates the examination of the theory associated with manpower utilization before the basic principle of measurement of productive time is examined. This research is not concerned with actual productivity measurement. The measure of productive time is beginning to be accepted as an alternative measure of labour productivity , thus it is essential to examine the concept of utilization and productivity.

2.2 THEORY OF MANPOWER UTILIZATION AT THE SITE LEVEL

Manpower resource can be examined from five characteristics, as outlined by Stainer (62) when he discussed manpower as a resource to an organization.

i. It is usual to aggregate manpower in quantity and neglecting the various attributes which can be classified and measured. However, manpower is not a homogeneous resource. While aggregate unit of manpower gives indication on the level of employment and the requirements for planning and forecasting of its availability, the attributes of manpower will provide managers more valuable information for the understanding of its non-homogeneity.

ii. Classical economists believe that the capacity to do normal work requires little knowledge or skill. This belief held by economists like Schultz (63) may no longer be accepted as valid. Manpower is now more knowledgeable. It is therefore vital to consider them as resource who can also decide what is best for them and thus manpower is also a decision taking resource.

iii. Manpower should not be considered only as a cost-consequence but also as an income-generator. This has more to do with accounting procedures. In construction, it is difficult to argue for manpower as an income generator. However both arguments can be valid. For example, the economic employment of manpower may reduce cost which subsequently increase profit margin and hence manpower as an income generator. The consequence of uneconomic employment will thus be an increase in cost and hence manpower can also be regarded as being a cost-consequence in this instance.

iv. Manpower is also a social resource. Its affairs must therefore be viewed from the impersonal and personal aspects as well as the wider aspect of human relations.

v. Manpower resource also consists of individuals. Individual motivation are influenced by a variety of factors; colleagues, work environment, managerial styles and many others.

These five aspects are by no means exhaustive. They provide an indication that manpower must be treated not only as a medium of production but also as a resource which is sensitive to the environment and external needs. Its management must therefore be more complex than any other resource management. Of particular interest are the assumptions of non-homogeneity of manpower and its role as a cost and income generator to the organization. Since manpower contributes significantly to the achievement of the primary project goal:

> "to build an optimum facility with acceptable quality of workmanship within a specified time frame and at an allowable cost" (64).

Its utilization must therefore be optimized (65). Manpower utilization will vary according to the needs of the project, resource availability and project characteristics. Utilization is defined either:-

i. "as making use of resources" (66) or
ii. "making practical or worthwhile use of something" (67).

According to Chambers Thesaurus (68), to utilize is either to

> "adapt, appropriate, employ, exploit, make use of, put to use, resort to, take advantage of or use".

Several aspects of manpower utilization are related to this research.

i. Labour productivity itself is usually associated with utilization of manpower resources.

ii. The measurement of time utilization and thus productive time utilization can also be construed as a measure of the extent of manpower utilization.

iii. How manpower can be managed will also determine the extent of its utilization.

Labour or manpower influence on a project will be significant because it is the only resource which must be employed in production regardless of the tasks as production is fundamentally labour dependent. Its influence will be more significant when production is labour intensive. Parker (69) claimed that manpower is probably the only resource customarily controlled on site, which may be understood to mean ALL sites. Harrison (70) cited that manpower problems were the causes of major delays in new power station projects of the Central Electricity Generating Board.

When a project is small and tasks are labour dependent, manpower is the prime resource employed (89). Manpower cost in this case will be proportionately higher while, its influence on scheduled target, the quality produced, and the productivity achieved will also be critical. It may be the only resource which is controlled and needs to be controlled. A reduction or an increase of one labour force may have an effect on the profit margin of the firm. A slight reduction in productivity of manpower force may be crucial.

When the project environment becomes large and more complex such as nuclear or electric power plants, material and plant and machinery may more significantly affect project cost and scheduled completion time and manpower cease to be the only resource to be managed effectively. However, manpower resource utilization must be maintained. This view is held by Anderson and Woodhead (71). The importance of labour productivity at this level can be summed up as follows.

> "...., the level of productivity attained by the labour force will determine the scheduled time for completion and the resources needed. The management of labour on site is principally concerned with quality, quantity, motivation and utilization within the planned framework. Manpower is the contractor's most precious resource and every effort must be made to avoid wasting it."(72)

The manpower cost component in a project is difficult to estimate from total project cost. Its real cost is usually not divulged because of the system of pricing in tendering and final accounts of projects. Contractors' records may be useful source of information. However manpower contributions to the achievement of the project goal measured from the yardstick of performance or productivity or quality achievement will be considerable. With these influences and consequences on project goal, manpower must be managed effectively. Its management must be considered from a wider aspect including maintaining productivity and quality.

Manpower management at the project or site level has seldom been approached as a total concept in the construction industry. Most of the aspects of manpower management at industry level such as manpower planning, forecasting and training may be applicable when applying it to the site level. The characteristics of the site and the behavioural aspect may require greater attention in the management of manpower resource at the site level. Management of manpower at the project level also need to take into account the type of firm under consideration.

Anderson and Woodhead (64) proposed a methodology of manpower management at the project level by combining the above needs. Manpower management is regarded as the management of people as a human resource and ranges over a wide spectrum. These can be classified into four major hierarchical areas; the human relations, personnel management and impersonal management of labour and industrial relations.

Human relations is concerned with aspects of individual human behaviour that relate to personality, skill level and requirements of the work environment. It is also concerned with the detection and resolution of issues that arise between individuals. Personal management of labour is concerned with face to face contact and management of small work group. Impersonal management of labour is concerned with the decision process and management effort associated with planning, scheduling, enumerating and performance monitoring of large groups of personnel. Industrial relations is concerned with the contractual and jurisdictional aspects of dealing with trades and organized labour groups, the availability of skilled labour and the terms under which individuals are hired, paid and worked.

Anderson's methodology focussed on personal and impersonal human management directed at the workplace, crew and project environment. The methodology will be varied depending on the differences in project team organizational structure, management roles, policies and decision making systems of small, medium or large construction firms. The functions which need to be carried out are in the process of planning, scheduling, allocation, work, monitoring and recording regardless of the above differences. This theoretical approach considers the management functions which should be differentiated from the actual techniques and know-how to perform. At the monitoring stage, the extent of manpower utilization against the planned and scheduled deployment should be checked. Most of the monitoring functions deal directly with manpower and should take into account the non-homogeneity of manpower. The functions can be a guide in monitoring and recording manpower utilization but any corrective action to be undertaken needs to be based on evidence. There are reasons why this should first be done. Thomas (87) forwarded three arguments.

i. Unless a problem can be adequately quantified and documented and can be shown to have cost advantages, management at the upper level is not anxious to change or modify practices to ensure improvements. Although it is difficult to establish the degree of reluctance, this presumption is not unfounded. Managers are sometimes too proud to admit their own mistakes, unless the mistakes can be proved and their effect on project outcome substantiated.

ii. Effectiveness of management in planning, organizing, leading and controlling work is the focal point of a cost improvement program and labour serves as the entry point into the system. Through labour, symptoms of much broader organizational and procedural problems can be identified. Labour reflects the symptoms but it has no control over them.

iii. A problem must be traced further down the system, so that potential dividends from cost or productivity gain can be realized. His argument must have been based on experience of the reluctance of management to adopt new practices to improve the performance of the project. This therefore necessitates a critical examination of their utilization.

Anderson's methodology must be differentiated from the aspects of manpower management at industry and national level where the treatment will differ substantially. Issues such as mobility, availability, general welfare and quality of working life may be more important. The process of monitoring and recording in Anderson's methodology are concerned with the utilization of the manpower resource.

One aspect of manpower management in Anderson's methodology is manpower planning and this is also an aspect of manpower utilization. Stainer (74) proposed a number of strategies in manpower planning which may be applicable to this research. The srategies are:-

i. The development of measures of manpower utilization as part of the process of establishing a forecast of manpower requirement, coupled if possible with an independent valuation.
ii. The use, where appropriate, of techniques designed to result in more effective allocation of work, as a way of improving manpower utilization.
iii. Research into factors that limit the contribution that individuals or groups can make to the organization with the aim of removing or modifying such limitations.
iv. The development and use of methods in the economic evaluation of manpower which adequately reflects its characteristics as an income and cost generator, hence improving the quality of decisions affecting the resources. The forecast of manpower could only be as good as the estimates on which they are based. Thus efforts on measurement of utilization must be devoted equally to those spent on forecasting.

A specific chapter in the book deals with manpower utilization though the treatment of the subject appears to be superficial if it is to be applied directly to the site level. Stainer's visualization of manpower planning is in the context of general organizational structure with no specific reference to the construction process onsite. However the four strategies listed above should apply equally well to this area and if these strategies are to be applied at the site level further work may be needed.

The work of both Stainer and Anderson is relevant for the understanding of the theoretical aspect of manpower utilization at the site level. Anderson's proposed functions which relate to manpower utilization, provides a good basis of monitoring the performance of manpower utilization. Whilst Stainer's proposed strategies could be applied to determine manpower utilization and plan corrective action. This understanding is essential because productive time is one of the many ways in which utilization can be measured. What is significant is the fact that many theoretical assumptions regarding manpower utilization can be assumed for manpower productive time. Using productive time as a measure of manpower utilization and applying Stainer's strategies is in line with the objective of this research.

Burgess (75) argued that good resource management, on and off site, increases productivity. Managerial responsibilities of manpower in planning, organising, controlling, co-ordinating, motivating and communicating to ensure good management were proposed. In addition, he highlighted the more common problems found on most sites, although each site in his view presents a different mixture of problems. Burgess's views are generally in agreement with those expressed by many writers who have discussed the theory of manpower utilization in general but always relating it to productivity achievement at the site level.

2.3 UTILIZATION AND PRODUCTIVITY AT THE SITE LEVEL

The level of productivity attained in the construction phase is one of the main factors influencing the success or the failure of the project (70). The basic goal of productivity is the achievement of the balance between the various resources which will give the greatest output with smallest input. The differences between manpower utilization and productivity need to be examined. Productivity is a multi-variate issue. When construction productivity is discussed, the nature of construction industry which differs from other industries (65) makes it a more complex issue.

The term productivity can be subjected to many definitions and it is confusing and unclear (76). Its measurement is usually in terms of input output ratio. The problem lies in what can be interpreted from this ratio. Previous review on the actual meaning of productivity by Fenske (78) and Shaddad and Pilcher (77) yielded no absolute definition. Fenske (78) rejected all the contemporary definitions of productivity; a mathematical ratio, a form of efficiency, a rate of return, optimum or effective utilization of resources, and having to do with production process, each with an argument. Instead he proposed that productivity should be defined as the magnitude of productiveness, which was then adopted by Shaddad and Pilcher (79). Since Fenske (78) made his review, the way construction perceives productivity is similar to that in other industries, which still use one of the above definitions. The more commonly used definitions in the construction industry are the ratio (80,81) or effective utilization of resources (82,83).

The utilization of resources as a definition of productivity has been rejected by Fenske (78), because utilization

> "is so general as to defy contradictions and comparisons provide no more than a vague impression of what productivity might be".

Effectiveness or efficiency of utilization of resources involve comparison to a standard and with regard to production it is a relative matter. He further wrote,

> "while productivity and efficiency sometimes are positively correlated, this is not necessarily true, anytime a resource produces it is productive, but it may not be producing efficiently or competently".

Bishop (84) on the other hand, perhaps recognising this criticism, argued that the primary use of productivity studies is not for absolute comparison. It is for relative comparison to yield an insight, so that it can inform management better, on ways which productivity can be increased. Fjosne et al (80) in defending the use of productivity ratio as a measure of efficiency, recognized that efficiency covers a wide field. However, they argued its interpretation as such, will help to clarify problems and concentrate on approaches available for practical realization rather than concentrating on pointless philosophical issues. Lowe (85) went further to divide the measure of efficiency into productive and allocative efficiency. The former is concerned with costs of production while the latter with optimal allocation of scarce resources.

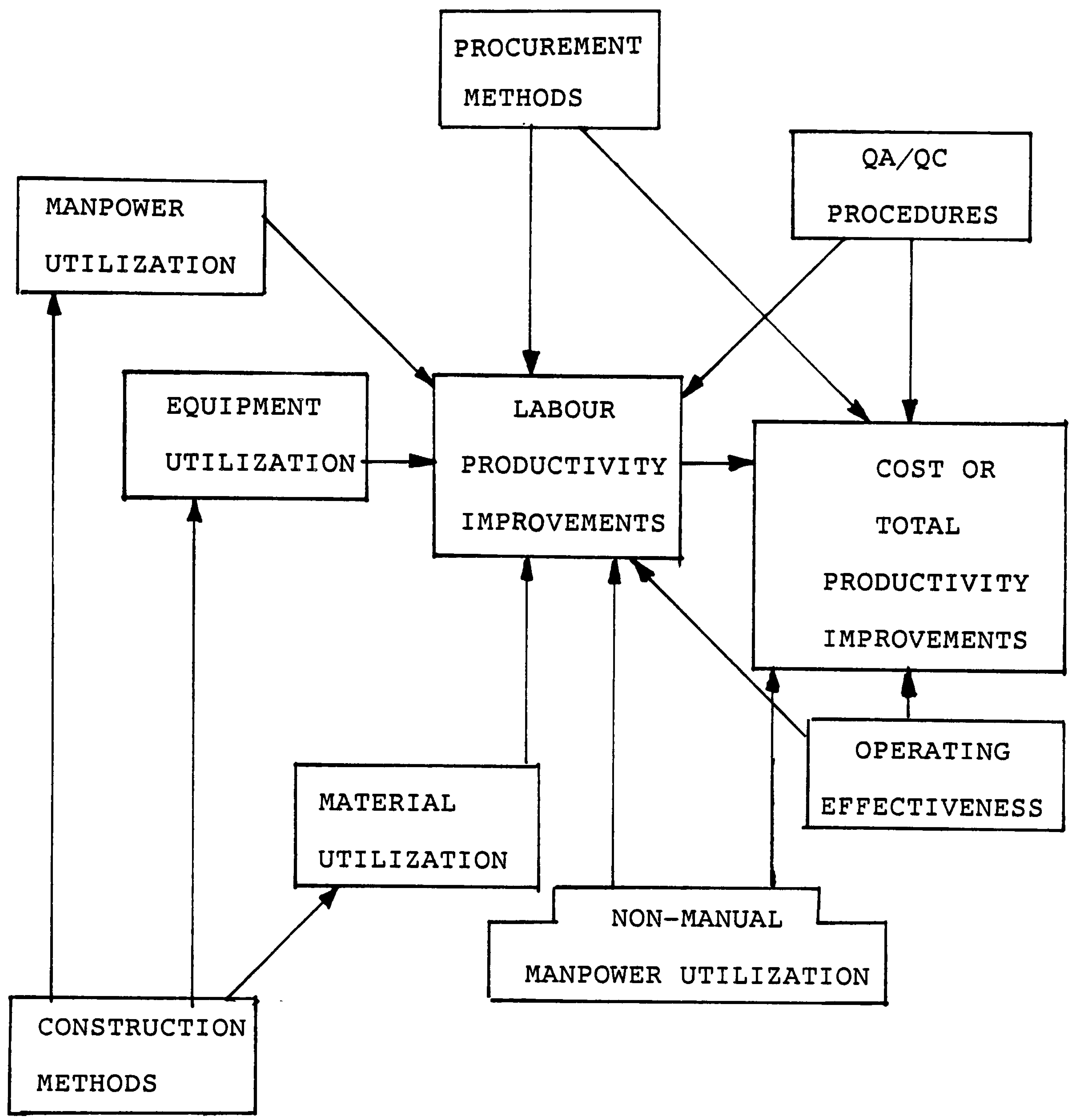
Productivity is not just a utilization of resources, its output represents perhaps some indication of efficiency in the utilization of resources. There is no doubt that Fjosne et al. (80) recognized the wider interpretation of efficiency and that Bishop (84) also recognized the relativity of comparisons as argued by Fenske (78). The definition of productivity solely as the measure of efficiency in the utilization of resources should therefore be rejected since the use of the term can be generally misleading. The conclusion then, consistent with all the various views, is that the delineation of productivity concept is still unclear. It is noted (86) "that construction productivity is a particularly difficult phenomenon to measure and indeed there is no universally accepted definition of productivity".

It would therefore appear that the issue of definition should not be considered as definite and foreclosed. In this study, it would be sufficient that the meaning ascribed to manpower utilization and productivity should be differentiated.

Manpower utilization is related to productivity as evident in Thomas's model of Cost /Total Productivity Improvement (Figure 2.1) (87). The model illustrated various components which can contribute to the improvements in cost or total productivity. Both manual and non-manual manpower utilization are components of labour productivity and consequently of total productivity. The source of any problems in labour productivity is thus related to manpower utilization. Productivity improvement is associated with the resources. Manpower utilization clearly affects labour needs and any improvement in these area will also lead to that of other area at the end of the system.

FIGURE 2.1

THOMAS'S SYSTEM APPROACH TO COST/CONSTRUCTION METHODS IMPROVEMENT



2.4 PRODUCTIVE TIME AS A PRODUCTIVITY INDICATOR

It is clear from preceeding section that utilization of resources is not a definition of productivity. It is one of the factors influencing productivity. The use of time utilization measures such as productive time as an indicator of site productivity is beginning to be used by some owners and contractors in the USA (88). This supplements the actual direct productivity measurement which may be more difficult to implement at the site level. Recent works reported have shown that it is a good surrogate measure of productivity.

Thomas (89) found that the direct work (productive time) when defined not to include some support works are highly correlated with the productivity measure used. Liou (90) also provide some encouraging evidence, that productive time is a good indicator of productivity although further validation may be necessary.

Most of the discusions have so far revolve around productive time as a measure of manpower utilization, as a factor of productivity and as a productivity indicator. Productive time measurement however owes its origin from work study in manufacturing, with production time concept used to discuss the influence of factors on production.

2.5 SUMMARY

The concept of productive time measurement has been examined from manpower utilization and productivity. These are closely associated. While productive time can be construed as a measure of the extent of manpower utilization, other measures are possible, such as the ineffective time. In productivity, productive time is a factor and a surrogate measure of productivity at the site level. The examination of factors influencing productive time has been justified and its usefulness clarified.

The complexity of productivity measurement at the site level can be positively thought of as being flexible because segregation of measurement is possible recognising the heterogenuous nature of resources of production. A clear and comprehensive understanding of the use and limitation of each measure will help to ease the complexity. As such the proper use of the term productivity must be made. The definition of productivity as efficient or maximization of utilization of resources is rejected. Although productivity data may to some extent help to explain the extent of efficiency of utilization its measurement reflect the magnitude of productiveness.

Manpower productivity at site level is significant. Its measurement should be made provided that the contribution and significance of other resources are recognized. Productivity, in the view of system's theorists must include all resources, although measurement of a single factor such as manpower is valid. The system's theorist view of productivity is fundamental in understanding the consequence of manpower productive time. This is because factors influencing productivity may be also be influencing productive time.

Manpower productive time is a form of manpower productivity measurement at the site level. It is however not construed as a true measure of productivity even to the extent of the true measure of manpower productivity. Its use as surrogate measure of productivity has still to be further empirically validated on a wider scale.

Measurement of manpower productive time could also provide a greater understanding on manpower utilization on site. Productive time measurement at the site level can determine the extent of manpower utilization. This could detect to a certain degree the efficiency of utilization. The theory that manpower utilization pattern can help to trace the sources of potential problems is adopted. Thus problem regarding manpower utilization and consequently on manpower management and management of the production process could be traced back to manpower utilization data. If productive time is used as a measure then by measuring and empirically establishing the influence of variables on productive time, the problem could be diagnosed. If the circumstances surrounding the production process can be numerically designed to be measured, the diagnostic process in the management of production could be founded on an empirical basis. The main issue now is how can it be achieved.

CHAPTER THREE

CHAPTER 3

3 MANPOWER TIME UTILIZATION MEASUREMENT

3.1 OVERVIEW

Time utilization measurement is developed from work study methodology. It is necessary to examine the principle of measurement to establish a foundation upon which this research can progress. The objective of this chapter is to examine the background theory associated with productive time measurement as there are problems in data analysis. It is possible that the associated classical theory has restricted data analysis to a certain degree.

3.2 WORK STUDY

Work study is a technique in the management of production process. Its origin can be traced back to the works of Taylor (91), the father of Scientific Management. Scientific Management as a branch of management philosophy is concerned with the efficiency of task performance (92). With this philosophy various techniques were developed, with a single and common objective of increasing task efficiency. Two other well known contributors are Gilbreth and Gilbreth who developed the method study technique in the process of production and are referred as the father of methods study (93). Both Taylor and the Gilbreth have contributed significantly toward increasing efficiency in task performance. Although, their techniques have now been largely refined by industries adopting them in many types of production processes, the ideas remain basically the same, and these are reported in much classical literature (94-103).

Work study in its basic philosophy is

> "the examination of human work in all its contexts, and which lead systematically to the investigation of all the factors which affect the economy and efficiency of the situation being improved, in order to affect improvement" (104).

This viewpoint is consistent with the Gilbreth's historical search for the 'one best way'. Two inferences can be made from the above definition; firstly, that the examination needs to embrace several techniques and secondly, it should be implemented with the right approach and a proper strategy. The proper application of the procedure would probably improve task performance but the 'one best way' is difficult to achieve.

Work study therefore embrace several well known and tested techniques, particularly method study and work measurements. Both play a different role, the former is about work procedure and the latter about time achievement. A combination of their application should theoretically affect improvement particularly productivity.

1.2.1 THE ROLE OF WORK STUDY -

Larkin (105) described the dual role of work study; the data collection and improvement of work. The former is the work measurement while the latter is method improvement. Their relationship is closely linked. The divergence between method study and work improvement is apparent although closely related in the way it is set to achieve improvement. For the construction industry, the emphasis should be on method study while work measurement should be treated in a supplementary capacity (106). This suggestion is in line with the general agreement of the difficulty of achieving valid and portable standard times for on-site production. Wide variations have been noted, and the absence of specific correlation even on some repetitive tasks have been discussed in Chapter 1. The necessity of standard time in estimating and resource scheduling for tendering and planning purpose must be recognized. Broomfield et al (107) for example, developed a framework from which performance allowance relating to achievement of standard time can be measured. The success of the use of standard time must be viewed against the norm of cost overruns and delayed work scheduled in construction projects.

In addition, there are many problems in the application of work study techniques on construction site as reported in a survey (108). More recently O'Neill (110) reported six findings which argued against the benefit of work study application in site production. This was strongly challenged by Wilde (109) who strongly argues for the benefit of work study. Only the problem of workers' acceptability and response remain as the obstacle in Wilde's opinion.

In practice however, the more common obstacle is in the technical merit of work study application. The interpretation of what a technique is designed to achieve may be debatable. Work study theory emphasizes the need for a number of techniques to be applied in order to achieve higher productivity. In other words, if only one technique is used over a number of operations or projects, and the results show an improvement in some measure of performance, such improvement can only be attributed to a particular role which the technique is designed to achieve. Therefore the conclusion must be qualified, to indicate no increase in other productivity component is measured, since a different technique is not used. Revay's (111) criticism on activity sampling, which is levelled without perhaps considering the basic purpose of the development of the technique may therefore be unfounded.

The non-monotonous nature of production in construction which may be causing high variation in productivity and productive time may also restrict work study application. Factory production is well defined and monotonous as such the philosophy can be applied relatively easier, although some problem, especially in the human aspects (112), still arise. The production process in construction is in work packages, which vary from projects, except perhaps in housebuilding whose design is rationalized. In addition most basic operations are short and is thus not suitable for extensive monitoring, even to determine the ineffective time within the normal statistical reliability. Therefore the application of subsequent techniques have to be applied to another operation which may not even resemble the previous operation in exactly the same manner.

Even if a particular operation is monitored in another project, there is bound to be variability in effective time and the variability may not be consistent. Thus the problem of portability of data weakens the practicality of work study at the site level. For housebuilding projects the philosophy of work study could be successfully applied theoretically. No empirical evidence has been found to substantiate this presumption. This may be due to a comprehensive effort required to derive a standard time for a particular piece of work. The problems highlighted above therefore, need to be considered prior to the application of work study for on-site production.

3.2.2 PRODUCTION TIME IN WORK STUDY -

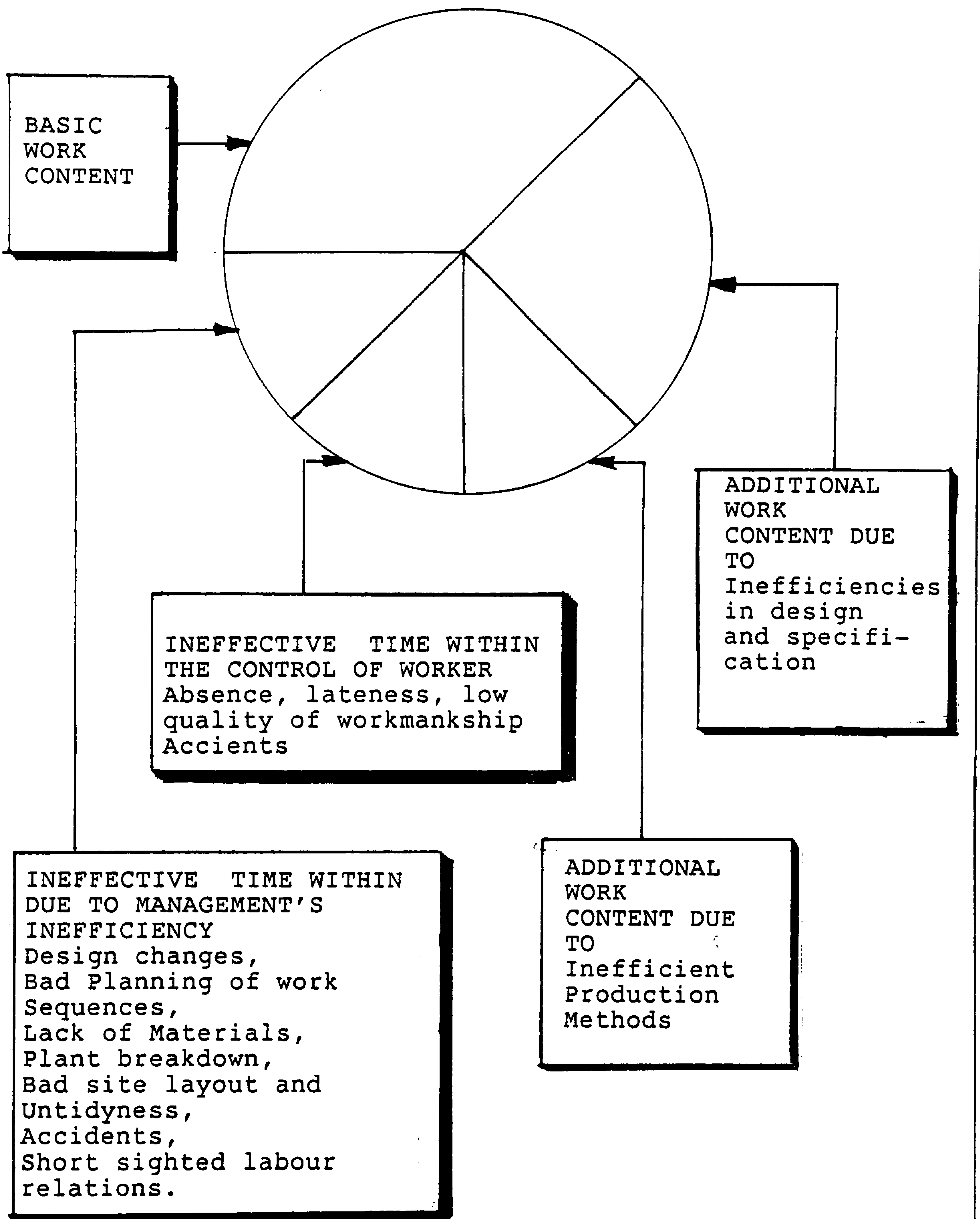
The aim of work study is therefore to affect improvement so as to increase productivity. Theoretically therefore, an increase of productivity can be attributed to the application of work study. The increase can be achieved when the production time of a task is reduced.

Production time is defined as the time taken to complete a process of production. When this is measured against a certain unit of output, the ratio becomes a productivity ratio. The time taken to carry out an operation or to produce a given quantity of output may be considered as made up of the basic work content, the additional work content, the ineffective time and the external delay. This concept is forwarded in the production time model. The model was first developed by the International Labour Office (113), showing the breakdown of total operation time. This was subsequently revised in a later edition to exclude the externalities component, which does not really apply to controlling the production process in manufacturing. The externalities component has to be included if the production time model is to be adopted for on-site production. Burgess (114) however, illustrate the production time model on site (figure 3.1) without the externalities component. Heap (115) also applied the theoretical idea specifically to construction process at the site level.

Production time needs to be reduced so that a greater amount of output can be produced within the available time. Thus the term basic work content is introduced. It is defined as the absolute minimum time theoretically required to produce one unit of output.

FIGURE 3.1

PRODUCTION TIME MODEL ON CONSTRUCTION SITES
ADOPTED FROM BURGESS (114)



This assumed a perfect condition and never occur in practice and the basic work content for all construction operations has never been successfully validated. Work study techniques produce standards which cannot be true, if operations differ in the factors that affect it. Thus the recognition of the large variability in manhour achievement. The work content is thus increased by the defects in design and specification and methods of production.

Work content added by defects in design or specification of product is due to features inherent in the product. Applied to construction, this is the buildability aspects discussed earlier. Work content is also added by inefficiency in the methods of production or operation.

The above three components assumed uninterrupted working; in construction work this is an exceptional case. Most reports in the literature have confirmed that interuptions to the production process on site are extensive. Thus the inclusion of the ineffective time component in the model, which may be due to two major causes:-

i. The ineffective time due to shortcomings of management. This may include the idle time due to the failure of management to plan, direct, coordinate and control efficiently.

ii. The ineffective time caused by circumstances within the control of the worker.

The ineffective time reduces productivity, but as has been noted earlier, the relationship has not been well illustrated for on-site production. The externalities as discussed may be due to weather effects and other factors beyond the control of management and operatives.

Production time can be theoretically reduced and productivity increased if the variables in the order of the significance of their influences can be eliminated or reduced. From the examination of the model, it is noted that the reduction of the influence of ineffective time caused by management and operatives should be done first. This could be followed by increase in efficiency of the production methods, and then by a search for the ways of reducing production time by proper design specifications.

The basic work content in on-site production cannot be derived from productive time measurement only. It include a proportion of productive time, indirect productive time and unproductive time. The proportion of these activities contributing to the basic work content cannot be easily distinguished. The derivation of the basic work content is however, not the objective of this research though the model will be useful later on.

3.2.3 THE ROLE OF ACTIVITY SAMPLING -

Activity sampling is closely associated in determining productive or unproductive time. It is generally accepted as a work measurement technique (113,102). However it has also been suggested as a data collection mechanism in method study (106). The difference is however a matter of opinion.

The application and extensive use of work study technique in site production has yet to be fully exploited. Many would agree that its use as a research tool will be more easily and practically applied rather than its use as a managerial tool. Callahan (116) examined the decline in construction productivity and discussed the need of productivity improvement techniques, especially activity sampling to reverse the trend of low productivity and eliminate efficiency caused by management failure. Laufer (117) reported the implementatiion of a site improvement programs applied to a medium size construction firm which include data collection methodology using work sampling for observations, questionnaires for survey methods and cost records for secondary data. Thomas (118) also proposed the use of activity sampling as a method improvement technique. Baxendale (119) noted that it is a way to measure the effectiveness of the site in using its resources. The purpose of activity sampling is generally agreed: as determining the degree of ineffective time so that management can take corrective action to reduce it. It is also recognized that because ineffective time is present, the extent of its impact on the production must be known. Hence activity sampling is used first before undertaking method study and subsequently work measurement.

Productive time data arise from measurements using activity sampling. This concept requires examination. The purpose of activity as part of work study to effect improvement is clearly defined. The main obstacle is the application of the philosophy to on-site production.

Activity sampling is perhaps the best technique developed for the measurement of time utilization by man and machine. The technique does not attempt to measure any variables influencing time utilization. The identification of how time is utilized cannot improve the production. When design rationalization was applied in studies reviewed in Chapter 1, the effect on the production process, must actually be measured, through a number of techniques and relating it to productive time or man-hour achievements in related tasks. The reduction in work content can only be determined by using the method study technique, instead of using activity sampling which measures time utilization and not measuring directly the effect of design. There is thus some concern over the adoption of activity sampling as a measure of the ease of production due to design rationalization.

Activity sampling is perhaps not suited for such a purpose. It can perhaps be further developed for the purpose of measurement of variables influencing productive time only if an in depth examination of its concept, uses and limitation are undertaken. An analytically established relationship could overcome the problem of transferability, portability of data and further extended use of the technique.

3.2.4 THE BASIC CONCEPT OF ACTIVITY SAMPLING

Several definitions have been put forward (120,121,122). The interpretations of the definition is more important than the way it is defined. Inspite of development in the technique and the modern version of the definition, Heiland's definition (122) forwarded more than thirty years ago, still holds true today. His definition also allows the interpretation of the basic principle.

From his definition, activity relate to the state or condition of an object at a moment when an observation is made. The state or condition is the action in the execution of an operation. With reference to human activity, this state or condition or individual moment during which a particular activity prevails, is the result of a reaction of a number of forces. These forces are both physical and psychological. The intereaction of one or more of these forces result in the human body showing the state or condition or individual moment. This is recognized by the observer according to his predefined classification or model of the activity state.

Sampling snaps the moment activity state. Basically it relies on the acceptance that at a certain level of confidence the results relate to the exact situation. Its practicality stems from the impracticality of continuous observation over a long period of time. The validity of the results at a certain level of confidence is reflected by the limit of accuracy within which the results are accepted. The exact situation may never be revealed by the results. At best, within its parameters, the results are what have been sampled. The acceptance of this fact must therefore be clearly understood from the initial stage of its choice as the data collection instrument. The true value of the technique lies in the capability of analysing a part as a representative of the whole, subject to statistical limitations. The two are inherent in nature. It must be clearly defined, understood, accepted but cannot be totally overcome. The limitation must be qualified and the parameters within which the whole concept can operate must be satisfied.

3.2.5 THE ORIGIN OF ACTIVITY SAMPLING

Tippet was responsible for laying down the foundation for the technique and this has not been disputed. Credit should therefore be given to him for making it possible to reduce the observation time and yet producing data which is reliable. The name of the technique has developed from the 'snap-reading method'(123), the 'ratio-delay method'(106), work sampling (96) and activity sampling. The differences in the use of the terminology however recognize the original principle behind Tippet's technique.

3..2.6 THE USE AND LIMITATIONS OF ACTIVITY SAMPLING -

Activity sampling has its limitations. Heiland et al (122) summarized four points not usually associated with work sampling studies:-

i. Work sampling does not include the basic information necessary for methods improvement.

ii. It does not give quick answer because of the need to satisfy statistical limitations.

iii. As a general rule no rating level is placed in observations.

iv. Again as a general rule no direct time per unit value are given.

The above points apply to the very basic form of activity sampling. The original development of the technique was to provide statistically reliable data on time utilization. Chapter 1 also examined the methods of data analysis and it is thus clear now that the current method of analysis follows the classical principle associated with activity sampling. Thus existing concepts are not flawed in anyway.

However, the objective of this research cannot be satisfactorily achieved if the classical theory associated with it is not critically examined. For example the reliance on unproductive time as an indication of the managerial and workers inefficiency is valid. However which of the two is more significant need to be determined. Since it has already been stressed that management in itself is made up of many other factors, the need to identify which is more important than the other in the context of productive time achievement becomes more important. In addition its use as a productivity indicator demand that the cause can be established through more quantifiable methods.

3.3 RECONCILIATION OF CONCEPTS

In order to achieve the objective of this research, the existing theoretical background of time utilization measurement must not be invalidated. There still exist considerable scope upon which the objective can be achieved. The common denominator in the classical theory of time utilization measurement is activity sampling. The classical concept of activity sampling needs to be adhered to but the interpretation of the data pertaining to productive time utilization can be extended.

Current analyses examine the time utilization from the unproductive rather than the productive portion. Time measurement is the first step in identifying the inefficient portion of a certain component of production in work study. It seems unrealistic to rely heavily on the assumption that unproductive portion of a certain operation or process is due basicaly to inefficient management and workforce.

In order not to invalidate the classical concept associated with time utlization measurement, this research propose to examine only productive time as a compound measure of the inefficiency in time utilization and disregarding other time utilization measurement. As such the causes of high unproductive time and indirect productive time may also be examined simultaneously. Thus the approach is to measure productive time and the factors affecting it without measuring other forms of time utilization as the masses of data produced by exsiting method has prove too difficult to interpret. An examination of productive time will allow more factors to be examined while retaining the original current hypothesis that unproductive time is a result of managerial and workforce inefficiency. Therefore, the inclusion of variables influencing productive time means that the measure or measures of the variables need to be designed.

The emphasis should now be on how to reconcile and present a methodology of measuring productive time within the production process and how to handle the measurement and analysis of its influencing factors. The examination of the above has to be done first before considering the approach to achieve the objective of this research.

CHAPTER FOUR

CHAPTER FOUR

4 AN APPROACH TO YIELD INFORMATION ON PRODUCTIVE TIME AND ITS INFLUENCING FACTORS

4.1 THE SITE PRODUCTION SYSTEM

Production is defined as

> "the creation or manufacture for sale of goods and services with an exchange value" (364).

This general definition also applies to site production. Site production however, is dissimilar in nature to production line processes or mass production in other industries, but is to some extent similar to job-processes in one-off-industrial production such as the aircraft and shipbuilding industries. Production line is defined as

> " a factory system in which parts or components of the end product are transported by a conveyor through a number of different sites (work place) at each of which a manual or machine operation is performed on them without interrupting the flow of production." (364).

The similarity with the aircraft industry lies within the production of one very large unit of output with the materials or components brought to one work place. Site production is however different from aircraft production in other ways. The production place in the aircraft industry is enclosed and is subjected to less influence of the external weather conditions. The design phase of aircraft production is longer and this enables the finer details of operations and work packages to be carefully planned and scheduled. Furthermore, ease of fabrication of components in aircraft production reduces the number of 'on-site' operations enabling a more comprehensive control and monitoring program to be undertaken. Fabrication for building production is much more restricted and thus the finished building will be dissimilar in nature from most other buildings of the same category. Other factors make site production unique from a one-off-industrial process. These include the usual large variation in resource input for most operations, the actual work place being part of the end product and the largely labour dependent operations. Site production is thus difficult to control and the management of site production more complicated.

To ease the understanding of site production, the application of system approach is considered as appropriate. This research views site production as a system by itself.

A system is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose (365). A system is often affected by changes outside the system. Such changes are said to occur in the system environment. In modelling a system, it is necessary to decide on the boundary between the system and its environment. A system will have a number of components.

An entity is an object of interest in the system while an attribute is a property of an entity. The collection of entities that compose a system for one study might only be a subset of the overall system for another study (366) The state of the system is the collection of variables necessary to describe the system at any time, relative to the objective of the study. An event is defined as an instantaneous occurrence that may change the state of the system. The term endogenous is used to describe activities and events occuring within a system, and the term exogenous is used to describe activities and events that affect the system. Systems can be categorized as discrete or continuous. A discrete system is one in which the state variable(s) change only at a discrete set of points in time. A continuous system is one in which the state variable(s) change continuously over time. A model is defined as a representation of a system. For most studies it is necessary only to consider some part of a system and a model is not only a subtitute for a system, it can also simplify the system (367).

Systems approach is a branch of contemporary management philosophy to solve the complex problem of real life and the approach could be traced back to the beginning of this century (368). Most notable of the pioneers is Bertalanfy (369-371) who developed system thinking. System thinking is adopted by many researchers in many discipline when faced with a given problem. For example, Checkland (372) developed a framework of system thinking to be applied in practice. His ideas were based on many case studies undertaken which tackle both the soft and hard system. Hard system apply to the environment in which the system is physical and static in nature, while soft system usually apply to a dynamic environment.

The emergence of system and contigency theory in the management of organisations has no doubt affected the views of researchers in the construction industry. The basis of this argument lies in the fact that construction work viewed from Checkland's idea is a soft system. A construction project inherits temporary activity systems and is most appropriate for the basis of system approach (373). The temporary nature of a construction project arise because the organization is created to perform certain specific tasks and is frequently disbanded when the task is completed (124).

Notable researchers that support this view include Higgins and Jessop (125), Morris (126), Cleland and King (127) and Nahapiet et al. (128, 129). However as Bjornsson (130) has noted, there is a lack of effort both to define what a system consists of and employ it to tackle the REAL world problems. According to Bjornsson, the first step is the development of a model of the system under consideration. Coats and Parkin (131) have argued for the use of model, particularly a computer based model, as a tool in research. Several contemporary models on a systems approach in organization have been developed. These include Kast and Roseinzweig's Model (132), Harding's model

(133) and Checkland's Model (134). These have been applied by many researchers in their quest for a greater understanding of a certain system.

The problem of defining a system is in the delineation of the system's boundary or parameter. Criticism is usually levelled at the extent of the boundary that a particular system can cover. Thus production itself can be considered as a system and the boundary specified will be valid in the context of the arguments presented.

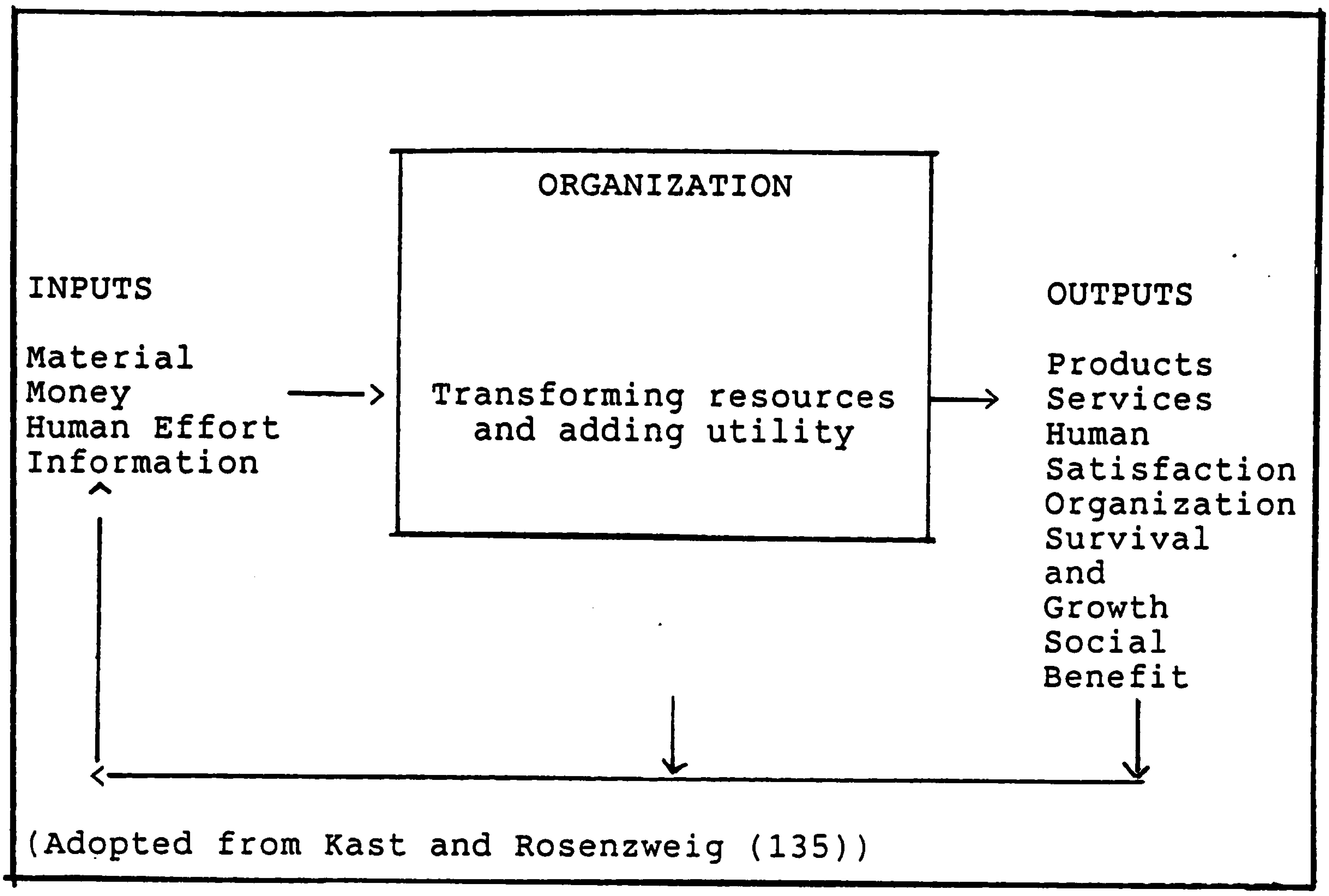
4.1.1 **PRODUCTIVE TIME IN SITE PRODUCTION SYSTEM -**

The basis of viewing site production as a system lies in Kast and Roseinzweig's idea of viewing an organization as a transformation system shown in figure 4.1 (135). The input include human effort and the output includes products. In addition, Drewin (136) has also viewed site production as a conversion system (figure 4.2). That the perceived system is only part of the complicated conversion process requires simplification. The production process should thus be viewed as a relatively open conversion system. Site production system defined herein is viewed as an open system. Hyde's graphical concept of elements of production is also useful in justifying the use of system to view production processes (137).

Drewin's model of production system is modified as in figure 4.3 for this research. In any system there will be a number of sub-systems or entities. Production process as a system therefore is made up of many entities. These include the transformation from RAW MATERIALS and COMPONENTS into unit of OUTPUT by MANPOWER or MACHINERY with the help of MANAGEMENT and METHODS OF EXECUTION. In this research, the input of human resources is measured from total time expended on site and the output from the productive time. Each sub-system or entity is made up of several attributes.

FIGURE 4.1

THE ORGANIZATION AS A TRANSFORMATION SYSTEM



(Adopted from Kast and Rosenzweig (135))

FIGURE 4.2

OPEN CONVERSION SYSTEM
(Adopted from Drewin (136))

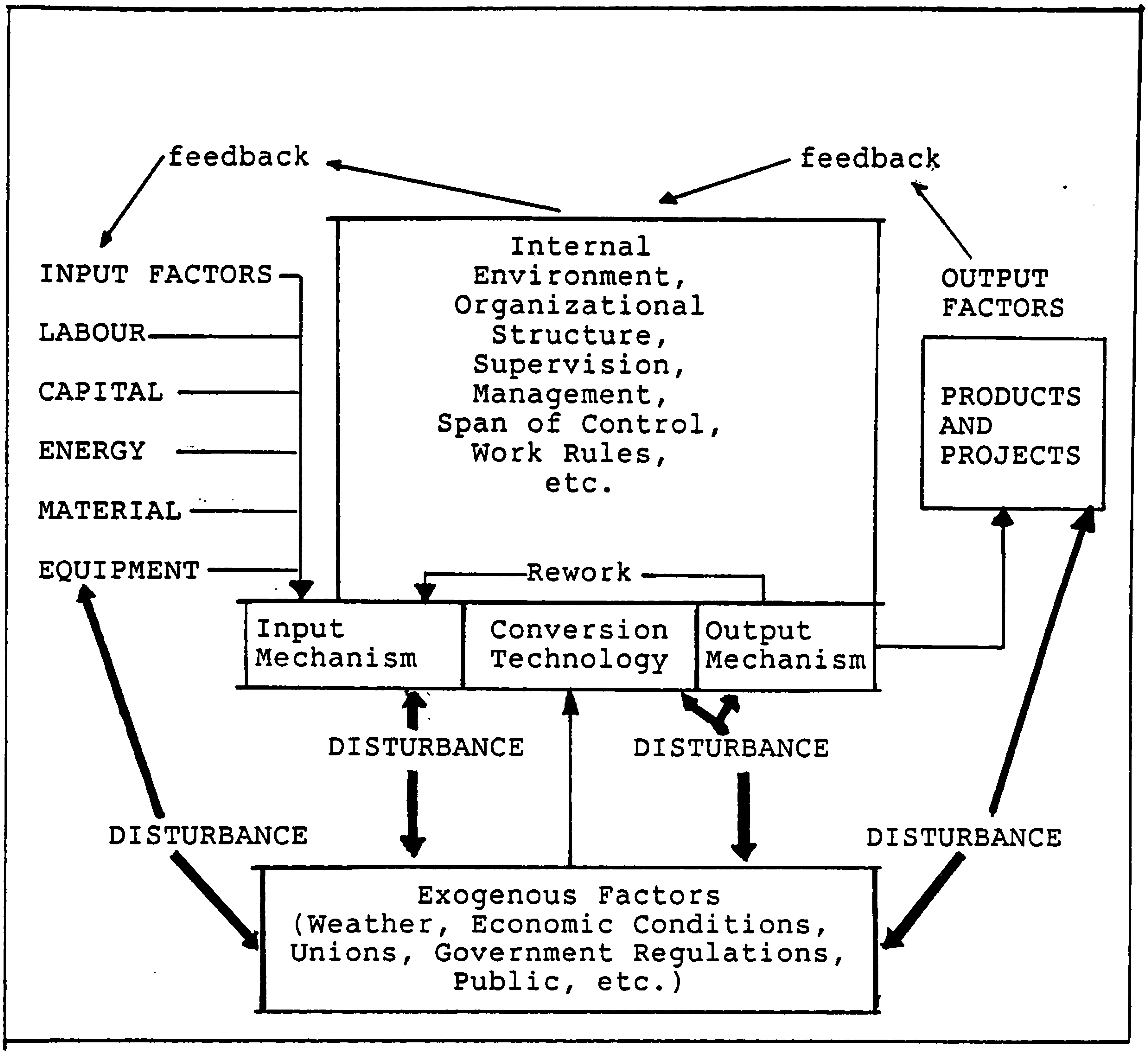
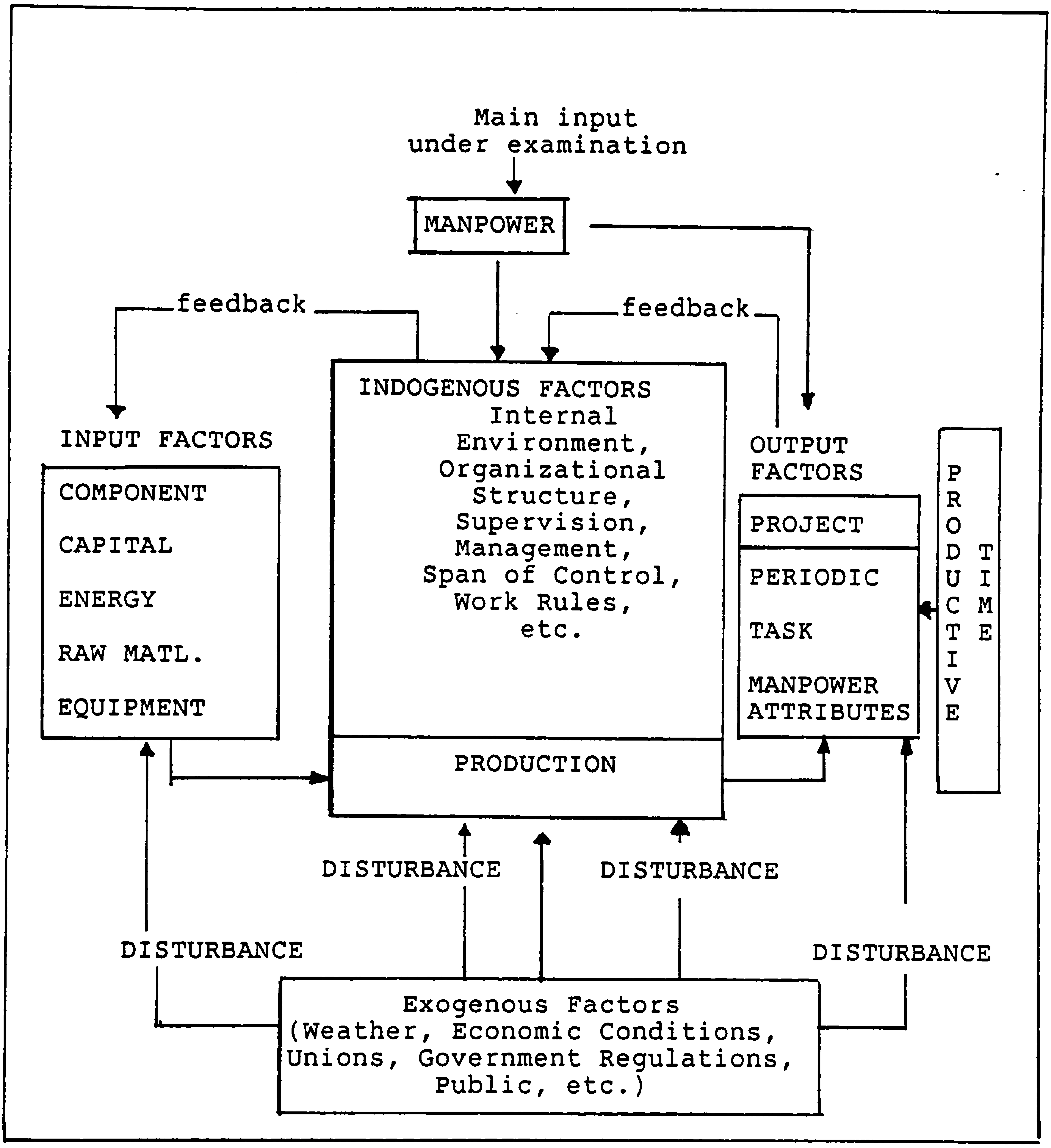


FIGURE 4.3

SITE PRODUCTION SYSTEM

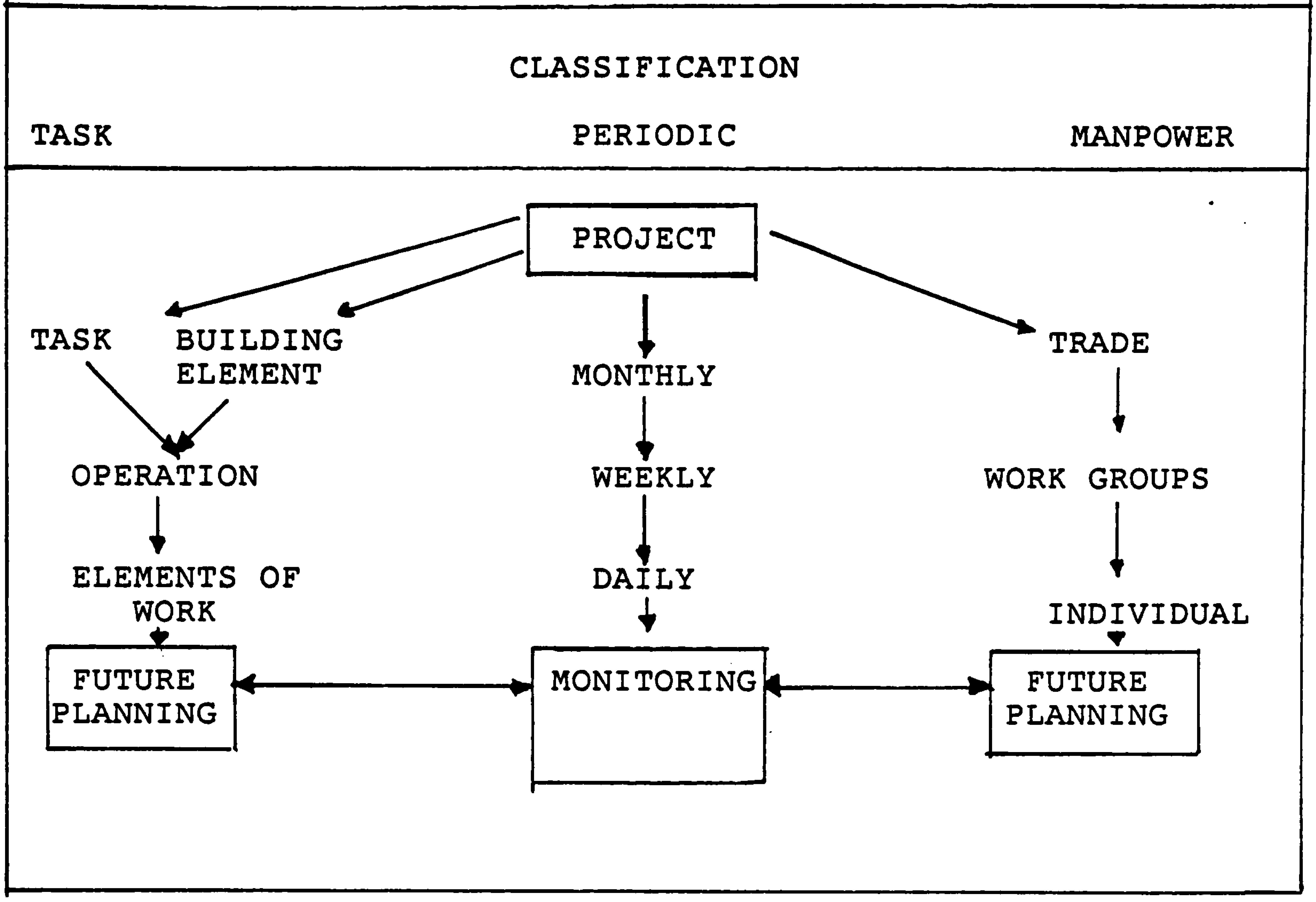


4.1.2 THE ATTRIBUTES OF PRODUCTIVE TIME -

Productive time is viewed as having three attributes; the task, manpower and periodic attributes apart from the productive time of the project overall. Task attributes are concerned with how tasks can be examined. These include appropriate classifications to standardize certain aspects of tasks. BS 3138 (138) classification of work for performance control defines a task, as an identifiable part of a job comprising a number of operations. An operation is defined as the smallest unit of work used for a planning or control purpose or a combination of elements. The element here is defined as the smallest piece of work activity (139). For cost planning purposes however, an element relates to the physical groupings of building fabrics. The operation therefore can also be related to the building element classification (140). Therefore, classification that is possible to be related to productive time is task/building element, operation and task element. This is hierachical in nature, with operation and task element being the lower level attributes as depicted in figure 4.4.

FIGURE 4.4

PRODUCTIVE TIME ATTRIBUTES



Manpower resource can be classified into individuals, gangs and trades, as proposed by Bishop (141) in explaining that productive time utilization is affected at three levels. At the individual level, operatives have to adapt to the pattern of other members of the gang as a whole and thus increase non-productive time in excess required by the normal rest periods. The high unproductive time from studies noted in Chapter 1 may have been due to the interference rather than abused rest period. At the gang level, progress of any gang will also be dependent on the progress of other gangs and on other constraints. This was established as significant in the Nuclear Power Plant study. At the organizational level, the utilization depends on the ease of redeployment to alternative work when orignal work is held up. The classification of productive time utilization has indirectly been forwarded by Bishop. However, productive time at the organization level, is not easily obtained as data from many sites are required. Further, it is suggested here that the level of productive time of trades can also be examined apart from the individual and gang level. The classification of manpower attributes is as depicted in figure 4.4.

In management of production, control of productive time expenditure to enable management to keep track of progress and detect possible problems is essential. Control chart and moving averages are useful, for the above purpose. Productive time therefore needs to be measured as daily, weekly, or any suitable periodic measure. The periodic classification is as depicted in figure 4.4.

Essentially then, there are three types of attributes of productive time which would enable detail examination of manpower resource productive time. For effective management of manpower utilization, productive time can thus be examined according to the two level as suggested by Stainer (142). The two levels are:-

i. The overall efficiency of manpower of the whole operation or very large sections of it measured in total and at the margin.
ii. The efficiency of different segment of the operation, defined in functional, departmental or occupational terms.

The attributes of a production process in relation to productive time are therefore based on the classification of the resource, the classification of the output or process and the data for periodic control. If many attributes of productive time are needed, then a database that can process the data to yield such information is basically required.

4.2 DATABASE

The invention of punched cards by Holerith in the 1880's probably started the use of the database as this was the first step in the development of computer technology (143). The first electronic computer then became operational in 1946. In the early days of computerization, the computer was mainly used for scientific calculations. A database is however essentially a large volume of data stored with its descriptions. The facility for storage and retrieval in a computer system was not considered as important during the early days of computerization. The problems experienced in the traditional filing system probably generated the need for database facilities in computerized form (144). From the early 1950's towards the mid sixties, the use of a database became increasingly popular and its concepts became more refined. The introduction of magnetic discs and its ability to read data directly instead of sequentially, boosted the capacity of the database system around that time. Thus data storage facility became more integrated and is readily and easily accessible. This therefore, made database a new and effective tool in the management of information. The concept of Management Information Systems also gained recognition around the mid sixties and by early the seventies a number of database management systems based on diversified data models appeared on the market. A database management system is now a logical medium in storing, integrating and retrieving information from data depending on what is needed.

The extraction of relevant information contained in data files can be done with ease when attributes are specified. In the most complex environment, database would yield information to model the real world and at the sametime can quickly respond to changes. The application of database concept is largely practical when the use of computer technology is available. Database management and the concept of Management Information System is therefore a very useful tool to store data and yield information.

In productivity studies, the latest use of database is made by Thomas and Horner (145) to measure productivity and other related data, with dBaseIII being used as the storing and processing medium.

4.2.1 DEFINITIONS

The term database has been loosely used in the past. Deen (146) defined database as a generalized integrated collection of data with its description, which is managed in such a way that it can fulfil the differing needs of its users. He analysed this definition into four parts:-

i. It is a generalized collection of data.

ii. It is integrated to reduce replications.

iii. It contains descriptions called 'schema'. A 'schema' refers to the description and storage structures of a database.

iv. It has to be flexible.

When evaluating a database system a prime consideration is the flexibility of the system to cater for differing needs. The flexibility can be achieved by structuring data along their natural relationship.

4.2.2 DATABASE CONCEPTS -

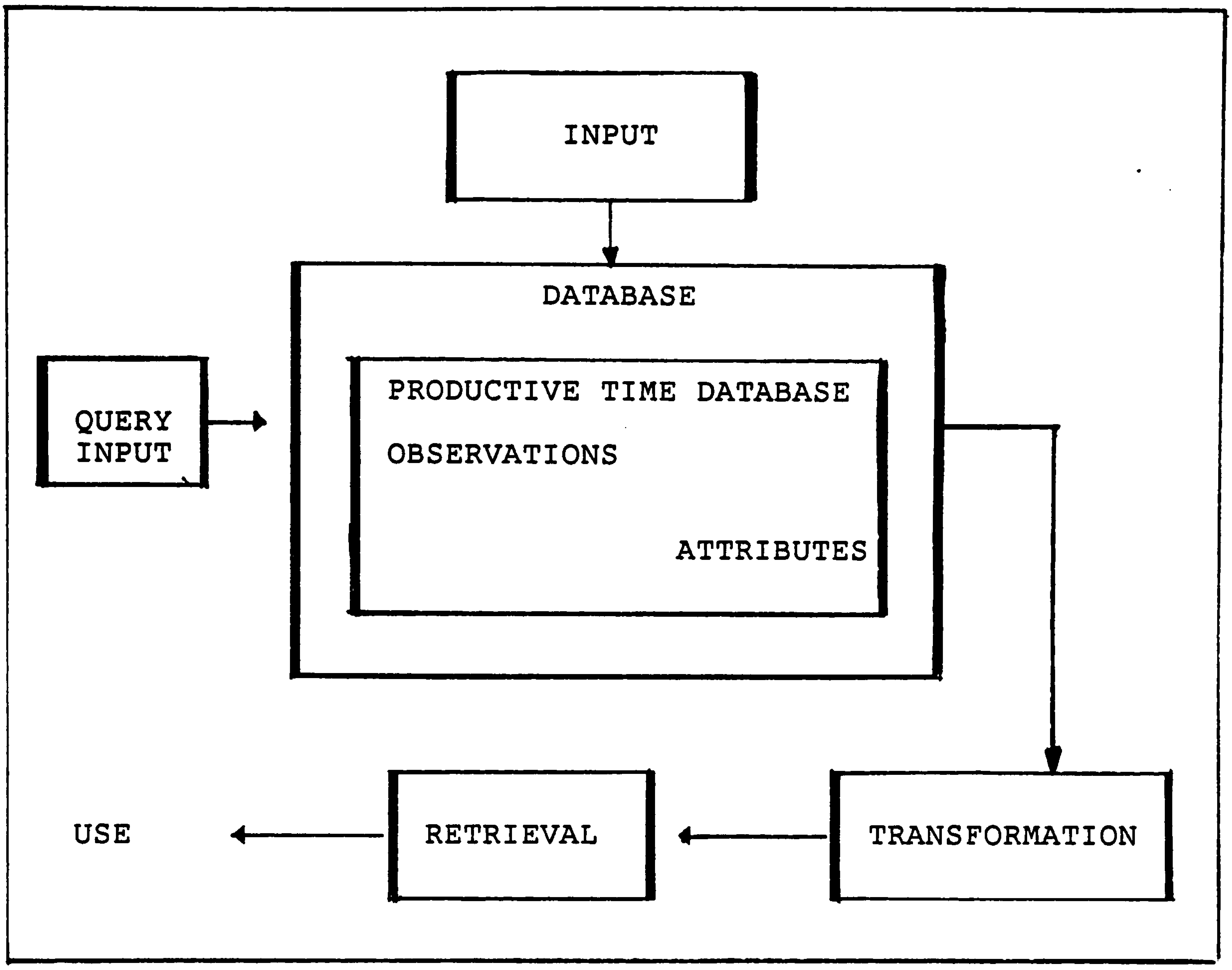
Data is the input into the database while information is the output obtained from the database after the data modelling and analysis. The term data modelling and analysis in the database must not be confused with that as used in statistical data analysis.

The concept of a database as forwarded by Burrough (147) is applicable to view productive time database. It is based on four components; the input, query input, transformation and retrieval. This is depicted in figure 4.5. The input will be the data on productive time collected at the site using a suitable technique. Query input will be the specification of the attributes mentioned earlier. The transformation will be the necessary calculation to produce the desired output. The retrieval will be the output obtained after the data is processed and transformed into meaningful information as specified by the query input. When the information on the attributes of productive time is available, the analysis process can then be carried out.

The four components of a database need to be examined in detail with respect to this research. In addition, the database must contain data which will yield information which can be related to factors influencing the attributes of productive time specified. Obviously, there will therefore be the need to look at the current application system which may help to solve the problem rather designing

FIGURE 4.5

DATABASE FOR PRODUCTIVE TIME
WITHIN THE SITE PRODUCTION PROCESS



a new database. The choice of available system and the potential that exist within a system to enable the objective to be achieved are two prime considerations.

There are many database management system (DBMS) which are available on the market (148). However none of the DBMS and the facilities available is considered. A system of data collection and processing designed specifically to produce output and information on productive time and manhours expenditure on production at site level is already available. Whether it can meet the requirement of producing the various information relating to the productive time has to be examined.

4.3 THE BRE SITE ACTIVITY ANALYSIS PACKAGE (BRESAAP)

Site Activity Analysis Package (BRESAAP) (149-151) is the more recent development of the random interval form of activity sampling. Other systems of data collection at site level which are based on activity sampling principle are the 'multi-moment' technique (152), the Group Timing Technique (153), 'The production follow up' (152) and various programs used in the USA (154).

BRESAAP is a data collection system that record and process data relating to on-site production. It can also be designed to suit a particular need. Most of the UK housing studies reviewed in Chapter 1 used the system to process the data. The principles relating to the use and procedures have been comprehensively documented (149,150, 155, 151). The review of this package (156-158), has generally covered various aspects including the concept behind the package development.

4.3.1 GENERAL DESCRIPTION OF THE PACKAGE -

The system of data collection can be made up of classification of manpower resources, management team, location of work, task classification and activity lists. This classification will help the observer to note and code seven types of data for each observation he made on an operative at the building site.

These are:-

i. Date
ii. Time of observation
iii. The operative identification number
iv. Location of work place
v. Element of work
vi. Operation of work
vii. Activity undertaken

These seven bits of information are coded on specially designed optically read marking forms (OMR). In addition two more bits of information specifically needed to ease data processing need to be filled in the OMR form. These are the observer identification number and OMR sheet number. The coding of information will have to follow the system of classifications which is in alpha numeric coding and which is defined as follows:-

i. OPERATIVES CODING

Each operative is allocated a personal identification number denoting his trade type and status. In this way confidentiality is assured. Data structure allows each trade type to be defined according to its status. Up to four levels of status can be accommodated.

ii. MANAGEMENT TEAM CODING

Management team personnel can also be recorded when they are on site. Their activity at the work place will also be recorded. Thus they are also given special coding so that, observations of their presence can be easily recorded. The same data structure can be designed as in operatives coding.

iii. WORKPLACE LOCATIONS

The building under study can be divided into areas of work and its coding can accommodate as many work place as possible depending on the design of the OMR forms.

iv. TASK CODING

The on-site production can be grouped in many ways. The coding usually used is a two part coding which defined the stages of work into 'element' and specific 'operations' within an element. The data structure for the task coding is hierarchical.

V. ACTIVITY CATEGORIES

The manpower activity categories can follow the normal activity coding for the Scottish House building studies and of the Health Centre project. A brief definition of the activities are given in Appendix A.4.

4.3.2 POTENTIAL OF THE SYSTEM -

One of the functions of BRESAAP is the measurement of time utilization. The main divergence from the basic form of activity sampling is in the information collected relating to on-site production allowing for other use (159,160).

The top down hierachical nature allows a maximum of seven levels of data to be observed and coded excluding the bottom level, which is the activity level. This level is independent of all other levels. The activities divided into 16 categories is the usual classification for an observer to easily 'snap' the activities. However the inclusion of the other seven levels of data in the package means that the observer has to remember and observed essentially hundreds of attributes. The argument over the maximum number of activities capable of being observed has not been justified as the succesful application of BRESAAP in many studies implied that it is possible to observe and record more attributes regarding manpower time utilization.

The observation of 'WHO', 'WHAT', 'WHEN' and 'HOW' relate to manpower, task, periodic classification and activities respectively. One of the activities is the productive activity.

The development of BRESAAP has not flouted the rules associated with activity sampling. The basic principles which are relevant to the technique were not overlooked during its development. The characteristics or parameters of an activity sampling technique are present in the package, thus it is a form of activity sampling.

Its potential capabilites resulting from the development must be recognized. The capability of the package in handling information relating to on-site production remained untapped. The original forms of activity sampling viewed from their use in work study, have their limitations. The development of BRESAAP was meant to surpass the original limitations but efforts have not been directed to make the information useful. Its use has also been supplemented by the recording of additional information (161,156).

Current application of BRESAAP has been relatively straightforward and restricted. The capability of BRESAAP has yet to be fully exploited. Its potential in handling and processing a large amount of data into meaningful information can result in a better understanding of on-site production. The theoretical consideration of manpower productive time can assist to produce tangible and desirable benefits. The processed data, can yield information that can be conceptualized as the variables influencing the productive time.

BRESAAP has not been described as a database, it is not the intention here to do so. However closer examination of the package reveal that it may be able to satisfy some requirements of a database although it cannot perhaps be classified as a DMBS.

4.3.3 THE CONCEPT OF DATABASE AS APPLIED TO BRESAAP -

BRESAAP groups its data structure into five main components for a particular project or sets of observations. For each observation, an operative working at a building site is observed. A data classification system regarding these components is assigned. Five main components are then recorded: the WHO, WHERE, WHEN, WHAT and ACTIVITY. These components can be further subdivided and detailed depending on what is needed for the research. The WHO will provide information on the operatives themselves and their status. After a long period of observations their productive time can be determined. If more operatives are sampled, then their productive time and other attributes can be collected and processed into various types of information.

BRESAAP could only satisfy three of the four components of database described. This is the input, query input and part retrieval process. In its current form it cannot transform data into meaningful information. It can however, produced semi-meaningful information based on certain attributes of productive time. Thus the retrieval process can only be considered to be partly satisfied. The main reason for this could be the lack of continuing improvement work on BRESAAP. No work by the BRE have been further reported on the continuing development of the package. Thus, data tranformation needs to manually executed or in other computerized form. However the package is considered as sufficient for the moment.

Several types of output are possible on productive time and other time utilization. These include the trade; the element; the operations; time of the day; location; weekly; and gang productive time in each element. Seven different ways of processing productive time are possible and can thus be considered as its attributes. This in general conforms with the attributes of productive time discussed earlier. The selection and identification of variables in a hypothetical model will determine the type of output needed. Care must however be taken not to use other activities directly as variables as they constitute a breakdown from the unproductive time proportion. In other words, data on other activities data from output tabulation from which productive time is obtained cannot be used directly as variables except in some circumstances as will be explained later.

For example output data on time utilization of bricklayer on an operation will also yield other activities apart from the productive time proportion. This must not be used. Other output data will yield information on whether or not they are the main type of trade employed for that particular operation, how much supervision was available, the number of other trade types working together, the interruptions to work sequence or period of execution and many more. It is these variables that have been measured and influence productive time.

Thus a critical assumption made in this research is that the variables can be measured simultaneously with productive time measurement employing the potential within the current development of BRESAAP.

However with the publication of CHILVER's report (162), no new development work will be done on BRESAAP because of the need to concentrate on other areas of research in BRE. Thus the research methodology will have to be formulated considering the existing ways in which data is coded, read, processed and produced.

This will restrict the conceptualization of more variables which need to be examined. Despite this at least 10 variables that influence productive time can still be examined. In addition, simple measures of other variables such as temperature changes can be made, provided the measurement are made at around the same time as the observation.

4.4 CONSIDERATION OF OTHER FORMS OF DATA INPUT

4.4.1 BASED ON OPINION RELATED -

Literature review on other methods of data input also found the use of FDS, interviews, and feedback from managerial personnel as useful sources of data. It is necessary to review the problems in using these these approaches, so that the decision to use a particular input mechanism can be justified.

Feedback on work time from various sources was applied by Sebastian et al (163) in the study of major factors affecting Nuclear Power Plant Projects in the USA. The study used various sources of information including questionnaires, interviews, discussion and meetings with foreman, managers and operatives. This option will yield vital information on the probable causes of productive time variation. However, productive time measurement may be a less effective. This is because opinions will be varied from different sources. The reliability of productive time measure will be less than activity sampling data. The results can thus be more questionnable, although it is a better way of yielding vital information as less time is spent for on-site observations. Using this option the confidence that can be attached to the measurement of productive time data cannot be easily quantified.

4.4.2 ;BASED ON OBSERVATIONAL DATA -

The observational methodology in data input is closely related to this research. There are two options, continuous or sampling methods of observations. Continuous measurement by observations was applied by Logcher et al (164). Continuous measurement is only possible for a simple and short operations. It may be the most effective, but may not serve many purpose unless many discrete continuous measurements are done. This may well be substituted by work sampling.

Work sampling or activity sampling will result in a considerable loss of information or circumstancial evidence which can be used to relate to productive time measurement. Theoretically, continuous measurement will have advantage over sampling but in pratice, sampling will still be favoured. Thus activity sampling is the practical and reliable method for the measurement of productive time.

Data input into database using opinion related and observational data needs a comprehensive work to create such database. This idea alone necessitates the resources beyond the capacity available for this research. Searching for an existing database or one which may perhaps have some functions of a database may ease the work load. This is because the objective is to measure the factors influencing productive time and thus every effort must be made to adapt and use existing capability of a tested computerized system.

4.5 THE NEED FOR A THEORETICAL MODEL

The gap that exists in the mechanism of data collection has thus been partly satisfied by BRESAAP, but the main concern is how the conceptual basis of the BRESAAP can be applied to this research. A theoretical model need to be developed revolving around the productive time, its attributes and its influencing factors that can be transformed from the data in BRESAAP.

There is as yet no theoretical model explaining the influence of variables on productive time which has been specifically developed. It is important to note that the thoeretical concepts examined in the last chapter have dealt with much of productivity from several contexts. Research approaches in productivity can be examined together with other approaches which may be applicable to this research. A few theoretical models of productivity and production time exist. These can form the basis of developing a theoretical model. The basic production process system as discussed in section 4.1.1 will be used to develop the theoretical model.

4.6 THE NEED TO DECIDE ON ANALYSIS STRATEGY

No statistical analysis to derive the conclusion on the causes of productive time variation has been forwarded. This is another aspect which must be examined, so that the conclusion can be quantitatively arrived at.

4.7 SUMMARY

The necessity of viewing productive time from its attributes have been put forward based on the idea by Bishop and Stainer and on the logic of such proposition. In addition the work of authoritative authors on systems concept have enable production system to be viewed as a system with productive time as one of its entities. Productive time within the site production process can therefore be examined from periodic, task and manpower classifications. These three main attributes can be further broken down depending on the need. Time utlisation measurement following the classical work study concept has not yielded much improvement either in research and practice. This proposition may be more useful for the management of on-site production. When the factors influencing productive time can be readily identified, its use can also be made to substantiate actual productivity measurement and the tracking down of the possible problems within the production process.

The Database concept was introduced so that data on productive time and its attributes may be processed and obtained. This therefore needs either a totally new database formulation or the use of an existing system which may be suitable. A component of any database is the source of input data. It was found that a combination of productive time measurement using activity sampling and other techniques to provide vital information such as FDS is useful. This however, will necessitate a complete undertaking of computational work dealing with the processing and dissemination of information for the attributes of productive time.

Data input of BRESAAP consist of data relating to time utilization, periodic data, task data and manpower classification data. The data structure of BRESAAP was so designed that all data are easily obtained with just a single piece of observation for one operative. The processing of the data in BRESAAP yield information which relates to some attributes of productive time. However because of the problems discussed therein, the information has still to be transformed to make it more meaningful. This requires further manual or computational work.

In addition, this research cannot progress if these ideas are not comprehended in a framework which can be the basis of the whole approach.

CHAPTER FIVE

CHAPTER FIVE

5 RESEARCH METHODOLOGY

5.1 OVERVIEW

The prime concern is to derive a quantifiable relationship between productive time and its influencing factors. This approach recognizes the difficulty of qualitative interpretations of masses of data, first reported in a study in 1965 (165). Qualitative data analysis problem is being overcome. Many researchers are now embodying research methods in the social sciences with the prior consideration of framework or model formulation or hypothesis set-up. Better design of studies to disseminate the data to answer certain problems is also required. However, there are those who argue against this approach, claiming that a study should collect all relevant data and then with available data consider the problems of analysis. In so doing, the actual picture of the situation will emerge and the conclusion will thus have to be drawn from all data. This should enable the problems associated with a given situation to be better understood. Both of these arguments have their merits and demerits.

Contemporary research methodologies now try to please and satisfy the arguments and overcome their demerits to a certain extent. One of the forms of methodology uses the systems approach, with models, database and statistical analysis. The systems approach, for example, takes into account all possible situations, while models will ensure that the investigation can be directed at a particular phenomenon. Databases on the other hand collect all relevant information and disseminate the necessary data needed for primary analysis but at the same time allows retrieval of relevant data when the need arises. The methodology used in this research may still be far from revealing the actual extent of the problems. The development of scientific ideas is a fluid process involving continued interplay between theories, hypotheses, observations and measurement (166).

The main problem involved in any research in construction site management is the lack of a suitably tested methodology especially in the data collection, whereas in the field of social sciences this is generally more refined. Methodology is defined as

> "the system of methods and principles used in a particular discipline or the branch of philosophy concerned with the science of methods and procedure"(167).

Thus research methodology is concerned with the methods and procedures in research. The term can also lead to a misconception that data collection methodology is the research methodology, whereas it comprises more than the data collection method. Helmstadter (168) for example, considered orientation, methods, tools and analysis as components of research methodology. There may be other views which will state different components to the research methodology. Data collection is only a component of the research methodology.

5.2 RESEARCH METHODOLOGY

The main research objective as outlined in the initial chapter can also be recapitulated from the title of this thesis which in general can also describe the methodology used for this research. This thesis is entitled

THE MODELLING OF FACTORS INFLUENCING OBSERVED MANPOWER PRODUCTIVE TIME WITHIN THE SITE PRODUCTION PROCESS

MODELLING is defined as the integration of problems into a framework of reference. Model in a given situation is any representation of the system under consideration (169). The system under consideration is the site production system. But the model formulation will only consider productive time. The term modelling also applies to the analysis methodology that will be used. Generalized linear modelling which is a general form of regression modelling will be used to ascertain the influence of the factors in the model.

The FACTORS referred to are the sets of hypothesized causes which influence the productive time. The use of the term factors or variables in this thesis will have the same meaning attached to them. The term system to denote that all possible factors have been taken into account is not used because the model is only a partial model.

INFLUENCING is a general term to denote that the factors can be positively or negatively influencing productive time. This will depend on a given situation, the extent of current knowledge of the influence of certain factors and the capability of the analysis methodology to generalize a given situation. In addition the term can be used to denote the aim of ascertaining the influential factors in a set of factors in the model and discounting the others in the model, given the data.

OBSERVED means that all productive time data originate from observation and recording made by the observer who will not be part of the production process. The observed data is on productive time. The factors are however derived from the observed attributes which will also be recorded by the observer. The use of the term observed also mean that the data collection system is designed based on the concept of BRESAAP.

MANPOWER is defined as the human resources utilized for site production excluding personnel involved in managerial, clerical and office duties.

PRODUCTIVE TIME is defined as the time observed in activity which contribute to the physical input of making the building grow. This is a very narrow definition of productive time and is used because of the indication that a narrower definition is highly correlated with productivity.

WITHIN is confined to the literal meaning which narrows down the scope of the research to a given site. Essentially therefore the meaning associated to it can be taken to mean that the model of productive time will have to take into account the possibility of examining all aspects of productive time within the site. This therefore justifies the inclusion and examination of database concept and the use of BRESAAP as if it is a database, although it is not a fully operational database system.

SITE PRODUCTION PROCESS is defined as in Chapter 4, thus the fabricated component and the actual process of manufacturing it is not taken into account. Pre-prepared raw material such as the ready-mixed concrete delivered to site will not form part of the study except when it has arrived on site. Literally what happens on the site physically covered by the site boundary and its fringes will be examined. For the purpose of this research no activity in the site office and the staff/operatives shed will be observed. This is done to preserve the industrial relation situation already established on the site.

5.3 THEORETICAL MODEL

Hull (169) also described several types of models: iconic, graphical, analogue or mathematical model. This views models as being quantitative in nature. The use of modelling in research regarding site level productivity needs a theoretical or hypothetical model as none currently exist. Certain matters regarding the theoretical model need to be evaluated before a model is conceptualized. It must be emphasized that the theoretical model is only part of the process of model-building, validation of the theoretical model is necessary to yield an empirical model (170).

The influence of variables on productive time can be formulated by developing a theoretical model. The theoretical model should provide a clearer understanding of the way the variables can influence productive time. In this research, it involves the formulation of a hypothetical relationship based on empirical evidence, theoretical and logical arguments. It will be developed, based on the following considerations:-

i. The available theoretical models which can be used to formulate the underlying theory. A critical examination will determine the degree of suitability to be adopted and applied as well as detecting their weaknesses.

ii. The nature and the limitation of the theoretical model to be developed.

iii. The understanding of how productive time and other measures of time utilization can be incorporated in the model.

iv. The understanding of how variables influencing productive time can be incorporated in the model. All except the second consideration will be dealt with in Chapter 6.

5.3.1 PRODUCTIVE TIME THEORETICAL MODEL-BASIC CONCEPT -

The existing way of measuring time utilization is focussed on the inactivity portion. Whilst it is of interest to know how time is spent by detail classification, what can be learned from the achievement of productive time has been neglected. The attention on inactivity does not provide a direct answer as to why a proportion of time was expanded on a particular activity. To pharaphrase, what contributes to the achievement of a certain level of productive time is not known.

The traditional way of measuring time utilization is only useful for determining how time was spent but do not help to explain the level of productive time achieved. A simple model of the reasons behind the variation in the level of productive time achieved and determined empirically is still non existent. Constructing a model needs the consideration of certain theoretical arguments together with how to empirically validate the hypothesized relationship. In statistical term, the measure of productive time is a response or a dependent variable. Its occurence is dependent on several factors. These are the independent or explanatory variables. The unproductive and the indirect productive activities cannot be used as direct explanatory variables.

A perfect model of classifying time utilization and its empirical relationship can be established by using regression modelling techniques. In this way the most influencing activities in relation to productive time can be determined but these are not what is required. They however form the most important source from which the actual factors influencing productive time can be ascertained. The explanatory variables relating to the productive time measure will have to be selected and measured based on the notion that they will probably cause the variation in the achievement of productive time.

A perfect model in the words of Blalock (171), is one in which the response variable must be regarded

> "explicitly as completely determined by some combinations of variables in the system".

Assumptions would have to be made in constructing a perfect model:-

i. That all variables influencing the productive time are known.

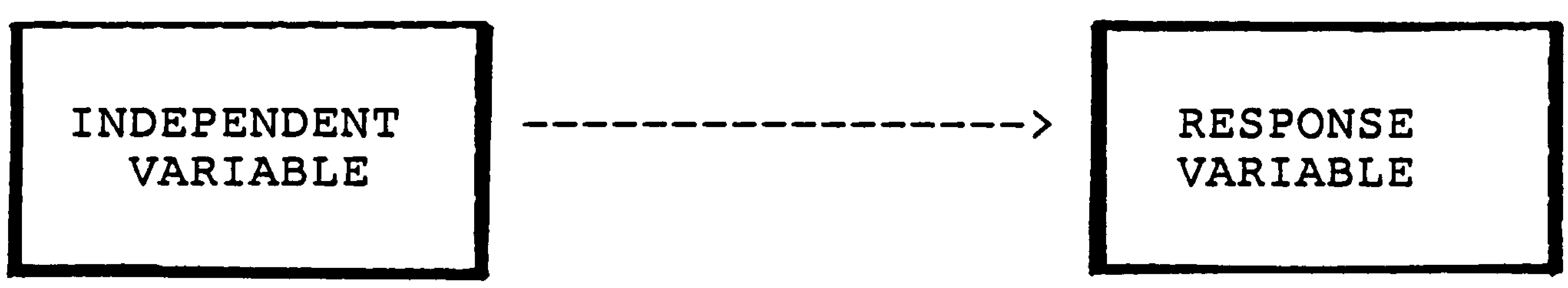
ii. All variables are capable of being measured.

iii. That the relationship between the variables and the ability to work are known.

In other words, how they influence, when they occur, the magnitude of influence and the direction of influence as well, as the relationship between the variables themselves are assumed to be known.

FIGURE 5.1

SIMPLE MODEL



The model would thus simply be as in figure 5.1. The model assume there is only one independent variable. The model would inevitably become more complex with the introduction of two or more variables. None of the above three assumptions can be validly assumed in this research. This is because not all influencing variables can be theorize as the influence of many variables has not been empirically established and not all are easily measured. Essentially therefore, the actual relationship and the magnitude of influence of most variables has not been validated.

A theoretical model can still be constructed, although the assumptions above may not be strictly valid. The model will however be a partial model because motivational and behavioural aspects will be exluded and not all variables are capable of being measured using BRESAAP. Causality is also not the main concern here, for as Kerlinger (172) states,

> "the study of cause and causation is an endless maze. One of the difficulties is that the word cause has surplus meaning and metaphysical overtones. Perhaps more important, it is not really needed. Scientific research can be done without invoking cause and causal explanations, even though the words and other words that imply cause are almost impossible to avoid and thus will occasionally be used".

He goes on to express his doubts about Blalock's (173) suggestion that even though empirically, causal laws cannot be demonstrated, it is still useful to think causally. Kerlinger was concerned that no amount of evidence can demonstrate causation.

Any model that will enable a causal relationship to be established must contain as many variables as possible. This number will be greatly reduced when some variables which are known to be influencing cannot be measured. Current analysis techniques also require economising on the variables which means as few variables as possible should be used, especially those that have a larger or stronger magnitude of influence. The reduction in the number of variables will make any research effort simpler if empirical data that support the theory is available, and thus the reduction can be justified. At the same time a parsimonious model will ensure that a conclusion drawn is based on a strong unqualified theoretical and empirical evidence.

The modelling of manpower productive time cannot achieve this parsimony by eliminating the number of influencing variables due to the lack of empirical evidence to justify their elimination. The choice of variables is also constrained with the use of BRESAAP and the decision not to develop a new measuring instrument. Hence the variables chosen will lack the necessary empirical evidence to support the model.

5.4 CHOICE OF TYPE OF STUDY

The importance of an intra-site study as against an inter- site study has seldom been highlighted. The influence of significant variables within a site can be easily identified, since it is within a site that many variables tend to be similar. Intra-site study will also provide vital information on how each site is managed. With careful design, many data points can be obtained, unlike in inter-site studies. It is estimated that as many as 100 data points could be obtained to allow for a comprehensive and detailed analysis, whereas, it is impossible to obtain 100 data points for inter-site studies which contain data on productive time and other variables.

The influence of variables between sites will differ substantially. Thus, if inter-site studies are to be undertaken, it is necessary to eliminate as many variables as possible. It is also difficult to obtain sites with similar characteristics which are constructed in the same time period as this research. The reduction of the influential variables between sites may thus be a fruitless attempt at getting the basic right.

The type of study chosen is the intra-site study, but several options exist on how to conduct the study. The measurement of variables is only possible through the process of collecting information when they occur. This means that actual events on site need to be captured and recorded as well as while measuring productive time.

A study of all ongoing site operations, at least in or around the area at one particular period of time is the most favoured. This will provide a large data base for the analysis of data in various ways. In practice this rarely can be achieved so a choice has to be made. This inevitably will affect the conclusions which can be derived.

Several options are available on how the study can be undertaken and can be divided into four: the study of single operation, specific operations, all operations or following the principles of work study.

For example Logcher and Collins (174) undertook a study of tile laying to determine the influence of management on a type of productivity measure. The operation was selected because tile laying is a simple operation and the influence of the management variables is easily modelled. The disadvantage of this approach is that although the circumstances surrounding execution of an operation can be comprehensively documented and measured, few data points can be obtained. Thus analysis which use statistical techniques may be constrained. In addition, when only a single operation is studied, conclusions derived could only be specific to that operation and this will not achieve the objective of this research.

Study of specific operations is more favoured by Thomas (175) because by studying specific operations,

"one can be selective and study only those activities that control the schedule or critical path activities".

Study of all operations will usually mean that operations which are critical may be recorded together with non critical operations and thus valuable data on critical operations may be lost. This is true especially when the design of the data collection system fail to measure critical operations. Thomas assumed that critical operations can easily be determined. This is true if the contractor's planning technique allows for critical operations to be known. Nevertheless, cooperation from the contractor to provide the necessary information to enable the measurement to take place is needed. Without this, the approach, although acceptable, may be less practical.

Studies of all operations on one site has mainly been undertaken by the BRE and has been reviewed in Chapter 1. Others not specifically reviewed were the productivity study in system school building :CLASP and SEAC (176,177), battery cast flats study (178,179),other housebuilding studies in UK (180) and studies of housebuilding productivity in Ireland (181,182).

The Building Research Establishment over a number of years, especially in the late 60's and the 70's also undertook a number of specific studies which generally follow the principle of work study. These studies are mainly concerned with that of bricklaying operations (183-187) and the rationalization of services (188).

5.4.1 STUDY OF ALL ON-GOING OPERATIONS -

A study of all operations in an intra-site study is more favoured than the rest. The reason for this choice are as follows:-

i. It will allow a thorough analysis of the whole site productive time. Although some operations may not be significant, their productive time must still be maintained. To concentrate on critical operations and neglecting the non-critical operations will not be a valid consideration from the productive time point of view. This is because optimum productive time level is essential regardless of operation types. Reduction in productive time in any type of operations will result in consequences already discussed in an earlier chapter.

ii. A study of all operations will allow a large data base to be built up. The extent of usage of data in the final analysis is a different matter. The measurement of all operations on site will mean a complete and detailed data on productive time from a particular site is available.

iii. Since the main objective is to study the influence of variables on productive time, the only logical choice will be the study of all operations.

5.5 DATA INPUT AND DATABASE

BRESAAP is chosen as the only measuring instrument in this study. Its untapped potential in handling massive data relating to on-site production will yield information on the attributes of productive time and its influencing variables. The data will be read and processed by BRESAAP as if it is a database. The transformation of the semi-meaningful information into the variables will be undertaken after the proccessing by BRESAAP. Chapter 7 will describe the data collection process and the database application to the observed data described in Chapter 8.

5.6 EXCLUSIONS FROM RESEARCH SCOPE

The following aspects are excluded from the research scope:

5.6.1 MOTIVATIONAL SUB-SYSTEMS -

Manpower productive time is also influenced by manpower itself through the individual worker, informal groups of workers and/or through unionized or organized labour. The individual and informal groups influence are from the motivational aspect. The motivational influence on manpower productivity have been discussed or examined by many authors. Borcherding et al (189-192), Maloney (193-196), Maloney et al (197), Mason (198), Laufer et al (199), Samuelson et al (200) and Weinel (201) are among those who have contributed to a greater understanding between the motivational factors and productivity.

The influence of motivational factors on productive time will also be considerable both from individual and informal groups. The methods of deriving the motivational influence on productivity cannot be accommodated by the BRESAAP and this group of factors will be eliminated from further discussions. In addition less theoretical arguments on the influence to manpower productive time are available but this does not imply that these variables are less influential.

5.6.2 **OTHER SUBSYSTEMS IN THE MODEL -**

The choice of BRESAAP has restricted the measurement of some other variables, as discussed in Section 1.3.3. The variables include tools and material availability, overcrowded working conditions, delays and work methods. These omissions will consequently restrict the generality of the analysis and thus the conclusions. The limited effects of omitting these secondary variables is further discussed in Section 11.5. Thorough examination of BRESAAP and its capability revealed that many information which relates to management, external influence, the manpower and the processes of production can be transformed and extracted into certain variables that may also be influencing the productive time.

5.7 **ANALYSIS OF INFORMATION**

The drawing of conclusions is only possible after the data has been analysed. The process of drawing conclusions then means that if a model has been developed in the beginning of the research and data has been collected, some form of hypothesis must have been set up in the model developed. Statistical data analysis should then be able to test the hypothesis tested.

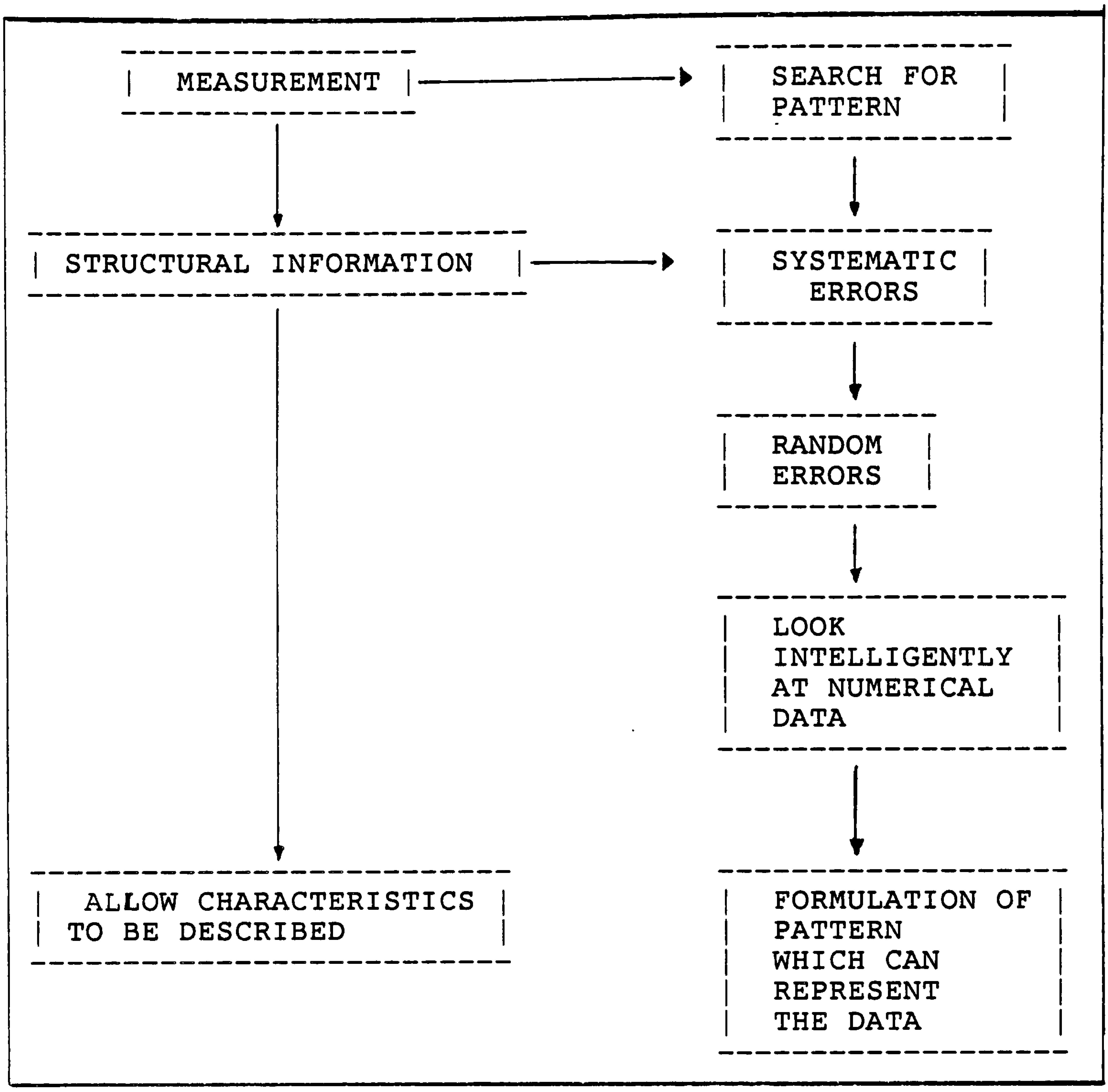
Statistical data analysis

> "is a broad field. It may include summarization of data and procedure for interpolation or extrapolation. It may also describe processes where data are used to support or deny certain relationship or hypotheses, i.e. as an aid in a choice of a theoretical or conceptual model. Statisticians have developed a wide variety of data analysis techniques, providing applications to virtually any field of study" (202).

Chapter 1 criticized the way in which the data is using normality assumptions or unusual trends to establish pattern or divergence in productive time achievement. Although in essence statistical analysis looks for a pattern, it does not however assume a specific normality. It may well be that the search for a pattern is to look for the unusual trend. In most cases a conclusion is drawn on the pattern produced by the data which can eliminate the influence of the unusual data. The unusual or normal pattern established can be attached with confidence limits and tested using various statistical tests. Thus when data is ready for testing to validate the theoretical model, the search for a pattern will investigate the cause of

FIGURE 5.2

THE PROBLEM OF LOOKING AT DATA



variation from the data which diverge from the overall mean of the sample or population. This testing will use algorithms developed and tested by statisticians.

McCullagh and Nelder (203), examined the problem of looking at the data from the statisticians' viewpoint. Figure 5.2 is a summary of their arguments. From this framework, it is clear that when data have been measured, the search for a pattern is necessary to arrive at any conclusion. The data will provide structural information, which will allow characteristics to be described. The structural information will contain systematic and random errors. If this can be accounted for, it will enable numerical data to be looked at intelligently to formulate a patterns which can represent the data. The hypothesis set up can then be tested using the data. The rejection or acceptance of hypothesis will be based solely on the evidence provided by the data. The process of data analysis includes model fitting, model selection, model criticism and model checking. The model used in the analysis must not be confused with the theoretical model. For clarity, the term model used during analysis will be referred to as the statistical model and during the conceptualization of variables as the theoretical model. Essentially this mean that the best statistical model obtained will be compared with the theoretical model conceptualized to validate the former.

The data from this study will contain one main variable and several independent variables. Thus regression analysis and its associated form may be the most suitable to be considered.

" Regression analysis consists of graphic and analytic methods of exploring the relationship between one variable, referred to as a response variable, and one or more other variables, referred to as predictor variables. Regression analysis is distinguished from other statistical analysis in that the goal is to express the response variable as a function of the predictor variables. Once such an expression is obtained the relationship can be utilized to predict values of the response variable, identify which variables most affect the response variable or verify a hypothesized causal model of the response"(204).

The main reason for considering the choice of regression analysis instead of other statistical tests is that regression analysis can be used to check and validate the theoretical model conceptualized and propose alternative solutions. For example if ten variables were conceptualized as influencing a particular attribute of productive time, then regression analysis should be able to confirm the influence of the factors taken as a whole. Regression analysis will also propose an alternative statistical model which can desribe the pattern of achievement of productive time better. Essentially therefore this analysis will not only validate the theoretical model but is a continuous process which make full use of the data and the theory presented. This means that although the ten factors theoretically influence productive time, the best sets of factors may contain less than the actual number which was postulated in the theoretical model. This implies that, attention should be given to factors in the best statistical model, because it explain the pattern of achievement on productive time better. The first consideration that should be given in any analysis is the nature of data.

5.7.1 **NATURE OF DATA -**

Time utilization is continuous in nature but as in many situations the measurement of data obtained from time sampling of activities are infact discrete because they are based on the binomial theorem of success and failures. Although it is usual to express productive time as a percentage, its use is for ease of comparison. This may not be as straightforward as it may seem, as most of the issues outlined above necessitate establishing the correct principles. For example if the normality assumption is required, the data collected should be normally distributed. However the binomial distribution has been used as a theoretical foundation of time sampling since the times of Tippet (205). If the data is not normally distributed the suitability of classical regression has to be evaluated.

Productive time data is a random variable and arises out of observations of manpower activities. There are two ways of classifying random variable; discrete or continuous (206). Continuous variable arise from a measuring process, while discrete variable arise from a counting process.

Observational data fits into the discrete variable category. Although if expressed in percentages, this falls into a continuous category. Discrete distributions include the mathematical functions such as the binomial, poisson, hypergeometric and geometric distributions. The continuous distribution include the normal or Gaussian distribution. The statistics regarding these mathematical functions are well described in texts such as Bancroft et al (207).

The binomial distribution applies to the productive time data in work sampling (208). However due to excessive probability computations and because many statistical methodologies are based on the normality assumptions in data, the normal distributions can be used to approximate the characteristics of probability density function of binomially distributed data. This provides the basis for classical statistical inference because of its relationship with central limit theorem (206). In this way, an estimation can be made of the standard error in the sampling by using the normal curve. Harper's text (209), as many other basic texts on statistics, describe the estimation of standard error for sample and population means. The assumption of using the normal distribution as an approximation to binomial probability distributions is true only when the number of observations are large and the probabilities are close to 0.5. The exception is that it has finite limits rather than infinite limits as in the normal curve (210). Berenson et al (211) provides more specific conditions and are as follow:-

i. The product of the two parameters n, (the sample size) and p, (the probability of success) equals or exceed 5.

ii. The product of n and probability of failure (1-p) equals or exceeds 5.

These conditions were specified for the use of the normal distribution. The reason for using this assumption was because of the difficulty of calculating manually the binomial probability distributions. When the conditions above are not satisfied, i.e the probability of the proportion of productive time does not fall within the normal limit of error, the problem in generating a valid pattern for hypothesis testing arises. The assumption that p is close to 0.5 can rarely be achieved even allowing for the normal two or three standard deviations. In inter-sites studies the assumption of normal distribution can be valid only for large observations but it cannot be determined before hand that p is going to fall within the standard deviation range acceptable. Another assumption in normal distribution is that the mean variance relationship should be constant, which may not allow the classical regression approach to be used. Thus when the variance is not constant with p fluctuating according to circumstances the use of normal distribution is not strictly valid.

While still using the normality assumption and taking into account the above problem, the response or dependent variable is transformed. For example the production time proportion (usually expressed as a percentage), can be transformed using the formula:-

$$Y = \log(p/1-p)$$

where p=proportion of productive time over total time, which is called the logit function.

It is not however, a general solution as the number of observations will not be large in all cases, even though Brenson's assumption only needs a small observation with high productive time. For example p of 0.5 will need n of only 25. Thus when expressing the productive time proportion as a percentage, the error created from the different number of observations even when the response variate is transformed is not fully taken account of. Strictly speaking the logit transformation can only be valid if the number of observations is constant. When it is not, as expected in the case of this study, with observations being made independent of groupings of variables, the testing of hypothesis can be principally misleading given this type of data. Hence the use of the percentages to express productive time is also a problem.

5.7.2 **UNIT OF MEASUREMENT FOR PRODUCTIVE TIME -**

Productive time and other time utilization data have customarily been expressed in percentages. The use of percentage as a unit can be misleading because the data arises out of a counting process. In using the percentage the discrete data is transformed into a continuous data, hiding the actual variation and the influence of a particular group of data. In addition, the assumption of normal distribution, to be used as an approximation, does not mean that the data can be transformed to a continuous measurement, although the actual time utilization is continuous.

The influence of a group of data can be hidden because a percentage is derived from a group of observations. If productive time is 55 percent it may arise from 400 observations or from 50 observations. The influence of the group with a larger observations will be more. In using percentages, this influence or the error which it carries is not calculated. So even if normal distribution is to be used as an approximation, the correct unit to be used is the number of observations productive for a particular group of data. When the actual counts of productive observations is used, the data will be widely varied. Even when the response variate is transformed to logit, the normal distribution cannot take into account the variance in the proportion, unlike the binomial distribution. The correct unit to be used for productive time data regardless of what distribution is used is the counts or the number of observation productive.

5.7.3 **THE SOLUTION -**

The solution to this problem has only recently been introduced, particularly with the advancement of computer technology to help in the numerous calculations which need to be done for binomially distributed data. Cox (212), Dobson (213) McCullagh and Nelder (214) have all emphasized that data derived from binomial counts should be analysed to take into account the binomial denominator, so that the proportion (percentages) analysed can accommodate the variance, while at the same time retaining the binomial probability distribution, inherent in the data. The availability of many statistical packages, has enabled the binomial probability distribution to be easily used in regression analysis.

Many statistical packages are available such as the GLIM3.3 (215)or GENSTAT5 (216), which can undertake analysis based on binomially distributed data. This type of regression methodology is known as the Generalized Linear Model (GLM). There is then no reason why binomial distribution cannot be used in the calculation of disturbances in the data when the facility is available.

5.8 GENERALIZED LINEAR MODELS (GLM)

GLM are essentially a generalization of classical linear models. Classical linear models originate with the work of Gauss and Legendre (217), which concentrated on the problem of variability in observations which were due to the effect of measurement error. The normal or Gaussian distribution was a mathematical construct developed from this work. Draper and Smith (218) and Seber (219) are excellent reference for work on classical linear models. Several assumptions in classical linear models are not applicable in the GLM.

Nelder and Wedderburn (220) first demonstrated the unity of many statistical methods involving linear combinations of parameters using the idea of generalized linear model. The mathematics regarding the GLM and its associated statistical properties are complex and will be described in simple terms without the loss of much information. GLM can be used to analyse other types of data, such as the poisson, gamma, negative binomial as well as the normally distributed data.

The analysis of binomially distributed data by GLM has been proposed by McCullagh and Nelder (221) and Dobson (222). The statistics involved are complex, but with the assistance of statistical packages and a basic understanding of the potential of the method, it can be readily used to analyse this type of data.

5.8.1 CHOICE OF STATISTICAL PACKAGES -

The choice of statistical packages that can be used to do the analysis is limited and only two packages mentioned above, are available on the university's central computer. GENSTAT was only available towards the later part of the analysis stage. GLIM was originally used, but was found to be slower in carrying out the analysis. With possible improvements and wider application of GENSTAT, it replaced GLIM in the final analysis. The change over from one system to another is not a hindrance as both systems can utilize the same data files without any adjustment, ensuring that there is no error in transferring data.

5.9 SUMMARY

This chapter has presented the methodology proposed for this research in general. Particular emphasis has been made on the potential of BRESAAP which will allow a database of production processes monitored to be built up over a period of time. The database can be processed to provide information relating to the circumstances surrounding productive time at the site level. The information can be theorize to influence productive time if a theoretical model concerning them can be developed. GLM will be used to analyse the data with GENSTAT as the mechanism.

Four main areas have to be focussed on and will be presented in the next four chapters before the conclusion and further evaluation of the whole research is undertaken.

i. Developing and conceptualising the way variables can be measured by the measuring instrument into a partial non-causal theoretical model based on the assumption that site production is a system. (Chapter 6)

ii. Designing and undertaking a study of all operations at a site level using BRESAAP as the measuring mechanism taking into account the variables that need to be measured, its validity, reliability and problems on applications. (Chapter 7)

iii. Transformations of relevant output data from BRESAAP into quantifiable variables conceptualized in the theoretical model. (Chapter 8)

iv. Statistical modelling of the data to determine the significant causes of variations in productive time. (Chapter 9)

CHAPTER SIX

CHAPTER SIX

6 PRODUCTIVE TIME THEORETICAL MODEL

6.1 OVERVIEW

The postulation of a relationship between productive time and the factors influencing it, is based on the current approach of developing a theoretical framework or model. Contemporary theoretical, simulation and empirical models related to production were examined as an initial step before the conceptualization ofa productive time theoretical model. It was found that most of the theoretical models were conceptualized along the understanding of natural relationship between the hypothesized factors and the response variable.

In construction productivity, Shaddad's (223,224) work, applying systems thinking, is the most notable and most recent, using modelling techniques and causality, but has not been empirically validated. Shaddad's model however assumed project management attempts an indirect influence on system productivity through its activities and thus management has no direct influence or control over system productivity. This assumption is vague and was not fully discussed in their work. Reference to other publications show that management has a direct and indirect influence upon productivity.

Bresenen et al. (225), for example, noted;

> " it is commonly suggested that apart from the significant direct impact of management upon productivity achieved by planning, coordinating and controlling activity, more effectively to provide conditions conducive to enchanced manpower productivity - management can have a significannt indirect impact upon productivity by increasing the satisfaction, morale and motivation of work force and field supervisory personnel."

Another recent method of analysing problems related with site level production is the simulation of data. Simulation modelling can generate the likely impact on a real life situation given the conditions included in the simulation and have been widely reported (226-231). Mathematical or factor model to assist the understanding of a particular phenomenon has also been widely reported (232-235). The modelling of a particular phenomena related to construction productivity is becoming a useful initial step in formulating a greater empirical understanding of construction work. Although each of these efforts has been constrained by many unavoidable reasons in the context of model testing and validation, the conceptualization of theoretical model must be regarded as an explicit step which must be formalized.

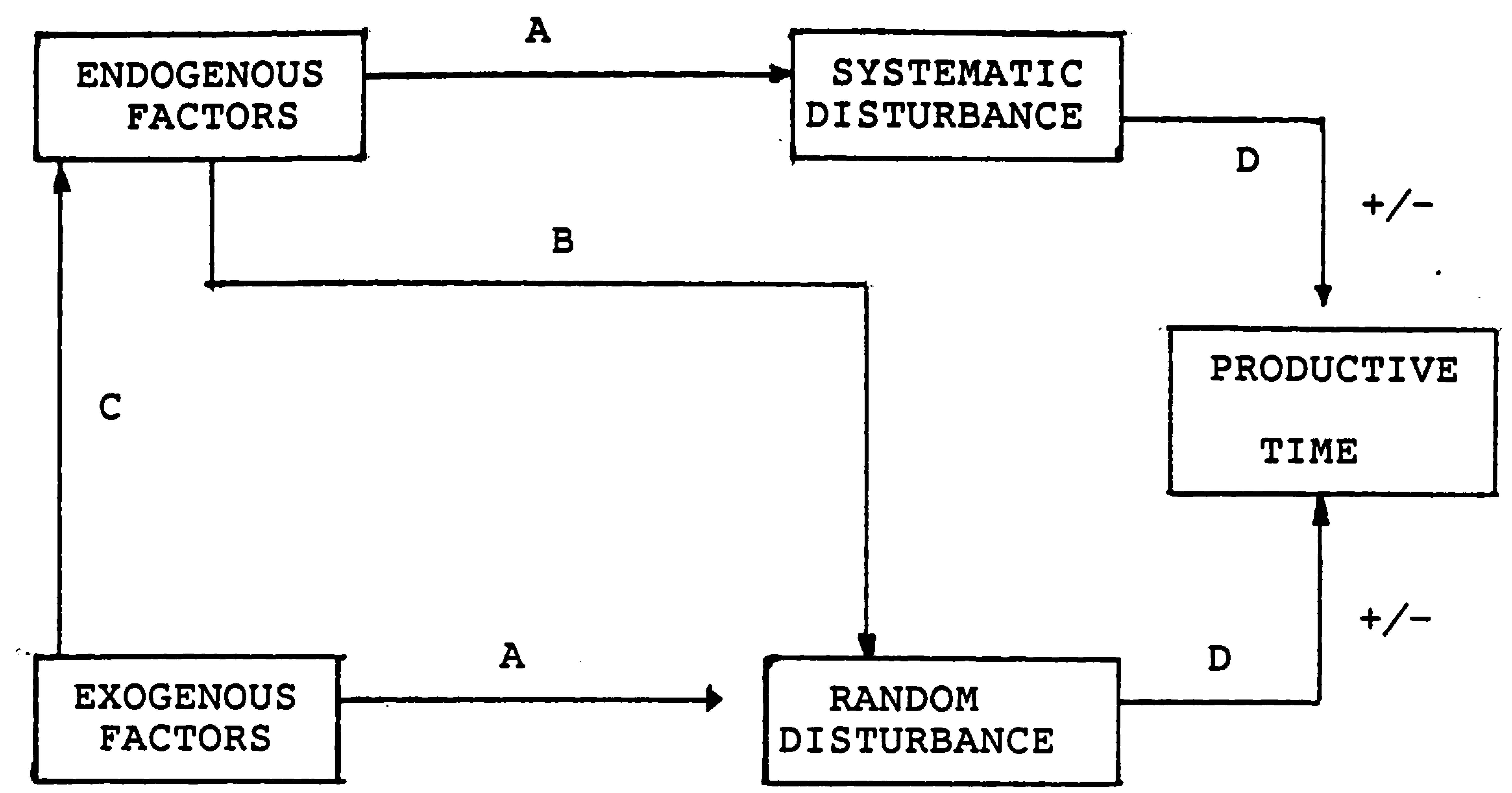
6.2 UNDERLYING THEORY OF THEORETICAL MODEL

The theoretical model assumed that the level of productive time achieved during site production will always be varied due to the influence of many and varied factors. The factors can be termed as endogenous or exogenous factors as explained in chapter 4. Endogeneous factors usually influence productive time systematically because of their presence in the production system. This assumption relies on Thomas et al. presumption (232,233). There are however, instances when their influence will be random. As an example, the decision made on the type of design will usually dictate production methods which may in turn reduce the optimum productive time that can be achieved. This is the systematic disturbance that will occur. The random disturbance may be the result of ad hoc managerial decision in resource redeployment during production which may lead to extra waiting and handling time hence reducing the productive time.

Exogenous factors are more usually associated with the random disturbances. A good example is the bad weather influence which is not in the production system but has to be taken into account because of its influence. This will also dictate the production methods and probably resources deployment. The random disturbances are usually short lived, but the cumulative effect of shortlived random disturbances may also be detrimental to the productive time achievement. The prolonged occurence of this disturbance will be detrimental, eventually forming part of the system when the disturbance cannot be overcome and further constrained site production.

FIGURE 6.1

STRUCTURE OF INFLUENCE OF VARIABLES



Note:
- A Main influence of relationship
- B Minor relationship
- C Exogenous factor becoming endogenous
- D Actual influence

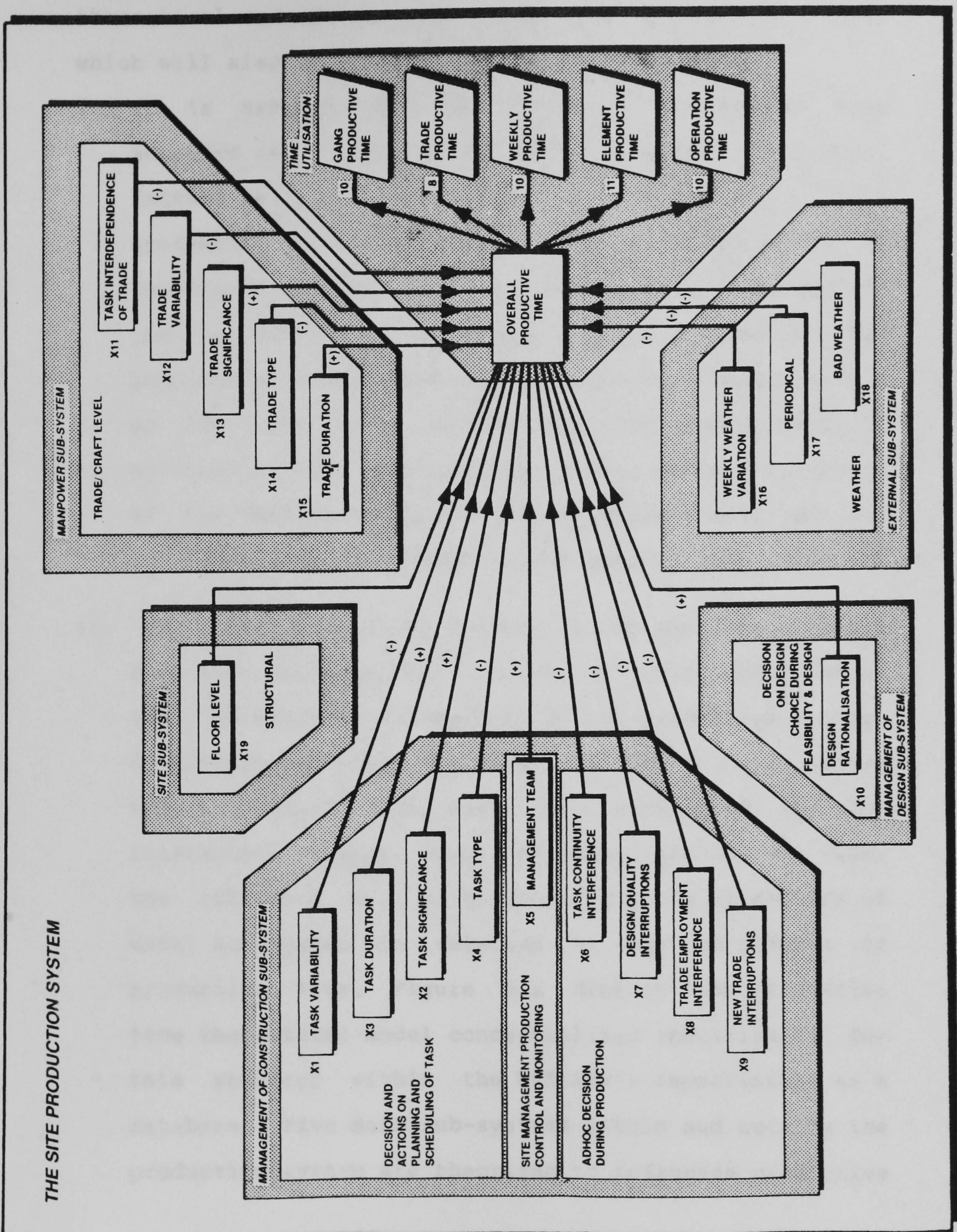

THE SITE PRODUCTION SYSTEM
MANPOWER SUB-SYSTEM
TRADE/ CRAFT LEVEL
X11 TASK INTERDEPENDENCE OF TRADE
X12 TRADE VARIABILITY
X13 TRADE SIGNIFICANCE
X14 TRADE TYPE
X15 TRADE DURATION
TIME UTILISATION
GANG PRODUCTIVE TIME
TRADE PRODUCTIVE TIME
WEEKLY PRODUCTIVE TIME
ELEMENT PRODUCTIVE TIME
OPERATION PRODUCTIVE TIME
10
8
10
11
10
OVERALL PRODUCTIVE TIME
EXTERNAL SUB-SYSTEM
WEATHER
X16 WEEKLY WEATHER VARIATION
X17 PERIODICAL
X18 BAD WEATHER
SITE SUB-SYSTEM
STRUCTURAL
X19 FLOOR LEVEL
MANAGEMENT OF DESIGN SUB-SYSTEM
DECISION ON DESIGN CHOICE DURING FEASIBILITY & DESIGN
X10 DESIGN RATIONALISATION
MANAGEMENT OF CONSTRUCTION SUB-SYSTEM
DECISION AND ACTIONS ON PLANNING AND SCHEDULING OF TASK
X1 TASK VARIABILITY
X3 TASK DURATION
X2 TASK SIGNIFICANCE
X4 TASK TYPE
SITE MANAGEMENT PRODUCTION CONTROL AND MONITORING
X5 MANAGEMENT TEAM
ADHOC DECISION DURING PRODUCTION
X6 TASK CONTINUITY INTERFERENCE
X7 DESIGN/ QUALITY INTERRUPTIONS
X8 TRADE EMPLOYMENT INTERFERENCE
X9 NEW TRADE INTERRUPTIONS
(-)
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Figure 6.1 depicts the type and structure of influence of the two types of factors. To summarize, there are three theoretical assumptions made for the theoretical model which will also apply to the analysis of the data:-

i. It is assumed that the level of productive time achieved is a result of the influence of several factors acting individually or simultaneously in a systematic or random manner. It is preposterous to construe that the factors which are to be measured are true reflections of the actual events influencing the productive time. They are only the best approximation of the real event surrounding the achievement of productive time. Further constraints to the reflection of the real events arise from database limitations and ill conditioned inference in analysis of data (236).

ii. The influence of the factors in the theoretical model have been based on the theoretical considerations of the influence of sub-systems in the production system. No attempt has been made herein to suggest the actual way in which each individual sub-system and the interaction between them influence productive time. The influence will be examined from the attributes of each sub-system in relation to the attributes of productive time. Figure 6.2 depicts the productive time theoretical model conceptualized specifically for this research within the BRESAAP's capabilities as a database. Five main sub-systems within and outside the production system are theorized to influence productive time and these sub-systems are as follows:-

a. The management of production/construction.

b. The management of design.

c. The site and structural.

d. The manpower.

e. The external sub-systems.

The arrows in figure 6.2 show the direction of influence of nineteen factors from all the sub-systems which will be examined. The model emphasizes the influence of the nineteen factors examined as one set of influencing variables. Thus, each sub-system on productive time is only included in the model for ease of discussions and presentation of arguments. This is because to measure the influence of each sub-system, a measure of each sub-system will have to be devised and cannot be achieved in this research.

iii. In real life system the influence of the sub-systems and their attributes on productive time attributes will always be longitudinal and its magnitude will vary with time. Longitudinal analysis of data should be able to approximate the circumstances better. All the analysis that will be done are cross-sectional analysis. Thus the influence of the factors will be examined from their total influence on each attribute of productive time, and not at the point of time in which they exert their influence. The theoretical assumption regarding the cross-sectional analysis will be that the influence of the factors will be in totality rather than continuous influence.

6.3 MANAGEMENT SUB-SYSTEMS

Management has been widely defined and the definitions are outlined below:-

"The coordination of human resources towards objectives accomplishment" (237).

"The group of persons who manage organizations. And also the disciplines concerned with understanding and improving the knowledge of how to manage" (238).

"Managing as the existence of something to be managed" (239).

"Management is a distinct process dealing with some form of group activity. Objectives are involved" (240).

These definitions refer to a process of accomplishing objectives or organizational goals by a group of people through the adoption of certain principles. It is a general hypothesis that productivity is a function of management (241-244). Management can be viewed to influence productivity from a number of viewpoints. Shaddad's management system (223), Harding's model and Kast and Rosenzweig Model discussed in Chapter 4 all examined management from various sub-systems.

Management at construction project level can also be classified into two separate sub-systems; the organization of the project and the organization of participants, groups or firms participating in the project. At the site level, the influence of both facets will be prominent. Both facets, have conflicting roles. Turin states that,

> "it would be nice to assume that participants shared a common objective and observed common rules for achieving them; unfortunately this is not the case, the building process is therefore plaqued with unwarranted assumptions, flouted regulations, parallel circuits, informal arrangements and ad hoc adjustments necessary to reconcile reality with abstract representation" (245).

6.3.1 **ALTERNATIVE MANAGEMENT SUB-SYSTEM** -

> "Management or the lack of it, is accountable for a significant proportion of the unproductive time that characterize the construction process" (246).

Hence effective management would increase productive time and hence lead to improve productivity, cost and profit margin. At the site level the influence of management on productive time will be substantial and their influence will be both from the project organization and organization of participating firms. The delineation of the influence of these sub-systems and the sub-system of other models will be difficult to ascertain.

As an alternative, management will be viewed from the following managerial sub-systems without separating the two facets of management in construction project described above. These are:-

i. The management of construction/production;

ii. The management of design;

iii. The management of design/construction interface;

iv. The general management of project.

In each of these sub-systems, a number of factors can be theorized to influence productive time. Only the sub-systems (i) and (ii) are considered in this thesis. The exclusion of sub-systems (iii) and (iv) does not necessarily mean they do not have any influence or bearing on productive time.

6.4 MANAGEMENT OF CONSTRUCTION SUB-SYSTEM

Management of construction will have a more direct influence on productive time through the functions they performed. The work of Fayol regarding management functions in early 1920's which was refined by many authors (239) was quickly adapted in construction management. Calvert (247), Pilcher (248), Oxley and Poskitt (249), Harris and McCaffer (250), Brech (251), Anderson and Woodhead (252) among many others, have all contributed to a greater understanding of the functions managers of construction at project level need to undertake.

Three main factors in this sub-system will be examined. These are:-

i. The effects of management decisions and actions regarding planning and scheduling of tasks.

ii. The effects of site management decisions and actions in control and monitoring.

iii. Ad hoc decisions during production in resource reallocation, quality, variation and production methods.

Each of these factor is broad and will be classified into further detail level. This is to permit the possibility of yielding information from the database and to achieve the objective of diagnosing the aspect of management which is probably influencing the achievement of productive time.

6.4.1 THE EFFECTS OF MANAGEMENT DECISIONS AND ACTIONS - PLANNING AND SCHEDULING OF TASK

In essence,

"construction project planning and scheduling along with communications of the plan have a major influence on the productivity of field crews" (253).

Planning and scheduling of operations is a process but communications of the planned task is another. Olson suggested that inefficiency is more frequently traced to shortfalls in both processes than any other single source of factor influencing productivity. Bad planning of work sequence is one of the reflection of management inefficiency (254). Olson reiterated that management errors in planning, scheduling and communication functions not only cause production delays, but actually slow down the subsequent production rate. This is due to the lingering frustations of tradesman who generally desire to achieve tangible accomplishments. Site planning has also been identified as one of the factors influencing productivity on large industrial sites with the important parameters being site layout and organization of work during bad weather (255). The work in the early years of productivity studies also indicated that some parameters in the planning and scheduling are responsible for increased productivity. These include good organization and work sequencing (256), improved advanced planning of site operations (257) and better control of timing of events (258).

This research is concerned with the planning and scheduling rather than communications. With respect to planning and scheduling the attention will be on the influence on productive time of what was planned and scheduled. How the plan was formulated is a different matter, but what has been decided and acted upon will influence productive time. Planning and scheduling of operations must take into account several parameters such as availability of materials (255), plant, tools and extra manpower (if needed), resource composition at the production level (223), work rate (259) and the task itself. Bishop (258) suggested that construction work should be geared to the creation of task-orientated structure of procurement. The significance of the nature of production task upon the achievement of perceived site performance have been expounded by Lim (260). He perceived that the nature of production tasks are multi-dimensional and attributed them to task variabilities, task dependency and task specialization. Lim viewed task specialization as the division of labour which is the horizontal differentiation of crafts or trades. Task variability as adopted from Hall (261) and Perrow (262) indicates that construction tasks experience a high degree of variability. Tasks interdependence is defined as the extent of connectedness amongst tasks. It is intended that the perceived influence on project performance be related to the productive time achievement.

Factors associated with the planning of operations are hypothesized as influencing productive time and capable of being measured. Adrian (246) has noted that poor project planning is one of the reasons for unproductive time. Errors or misjudgement in this process will lead to delay and reduce productive time. Unbalance gang size or late delivery of materials, for example, will lead to temporary idleness and extra waiting time for further instruction to re-deploy manpower. It is therefore imperative that planning and scheduling of task and especially the nature of the task is forwarded as one of the factors influencing productive time. The influence of task will be examined from four aspects:-

i. TASK/OPERATIONS VARIABILITY

Task/operations variabilities (263) can be measured from the number of operations because a greater number of operations will indicate a greater task variability. A greater task variability will necessitate frequent change-over from one operation to another and consequently needing new task planning, preparation and work place set up, in addition to travelling to the work place. Hence operation planning should reduce task variability but this inevitably reduces the number of stages of work (258) which makes production more difficult to control due to larger number of resources utilized. Reduction in task variability will enable the achievement of a higher level of productive time. Since the nature of construction work involves high task variability, task variability is postulated as negatively influencing productive time.

ii. TASK/OPERATIONS SIGNIFICANCE

The operation planned for the period under study can influence productive time through its importance to the scheduled target. If the operation is significant to the scheduled target then management will ensure that it is completed on time. This will be in line with the suggestion from Thomas (265), that critical operations should be monitored to avoid delay. Thus indirectly, high level of productive time should be achieved. Therefore certain types of operations should have high level productive time. Operation which is less monitored because of their relative insignificance to the progress of the job will have lower productive time.

This assumption is based on the notion that management will plan the significant operations within available resources. Non-significant operations will be left with the left-over resources. Although faster progress may be achieved, the productive time of non-significant operations need also to be maintained. If this assumption is true, the non-significant operation should achieve lower level of productive time. Although this may not cause delay, a large number of uncontrolled operations, not significant to the scheduled target, will reduce overall productive time and hence may further reduce productivity. Therefore, measuring the significance of operations or tasks may yield the information on whether the task dependancy can influence productive time significantly. Highly significant task/operations will influence productive time positively.

iii. TASK/OPERATIONS DURATION (CONTINUITY)

Continuous working is paramount to the achievement of higher productive time. Essentially this necessitate the creation of conducive working environment for continuous working. One such parameter is forwarded as the continuity in task execution. Interruption to task execution has been identified as one of the factors influencing productivity

(264,266) which originated from the assumption that continuity of task execution is paramount to productivity achievement (267, 256). In as far as productive time achievement is concerned, the continuous working for a particular task is significant. However because of the database limitation of yielding the actual duration of each task in detail units, their influence will be measured from a broader parameter, for example in terms of weeks rather than the actual hours. A high degree of continuity in a particular type of task/operation should influence productive time positively.

iv. TASK/OPERATIONS TYPE

The variability of productivity is fundamentally associated with the nature of the construction task. The nature of task influence may be tested from a number of parameters such as cyclic, periodic or random tasks. Another parameter is the task type. The classification of task can be hierarchical. Each task can be denoted by a classification, followed by building element classification and the main element classification. The influence of each task type will be examined only from the main element classification, due to the problem of interpretation and subsequent interaction effects.

In addition, it was observed that there were more problems during construction of suprestructure and services elements which led to many occurences of inactivity observed and recorded in the Diary Sheets. Some of the problems were in the laying of the precast concrete slab for suspended floors, reinforcement fxing to suspended floors, wall cladding, roof cladding and floor laying sequence of construction, staircase construction, internal plumbing, acoustic chambers, trunking for electrical cables and piping for heating. Some of these problems should have been taken into account by other variables in this subsystem. However, the problems may also be accounted for by the nature of tasks. The decision was thus made to group the tasks in these elements together and to examine the influence of the tasks in terms of their broad classification. Thus for the purpose of this research it is postulated that the execution of tasks within the two main elements have been constrained and thus their productive time may be lower relative to other elements. It should be noted that other combinations for the task can be made but is not considered necessary because of the reasons dealt with above.

The horizontal dimension of task specialization is concerned with the concept of division of labour and will be examined in the manpower sub-system. Furthermore, planning and scheduling can only be successful when production is controlled and monitored. Bishop (259) stated that planning is associated with control. Without control, resource will not be available at the work place on time. Planning and scheduling also need ad hoc managerial actions. The influence of both will be discussed in the next two sections.

6.4.2 THE EFFECTS OF SITE MANAGEMENT DECISIONS AND - ACTIONS IN CONTROL AND MONITORING

Control and monitoring are two processes recognized both in traditional and current thinking of management processes (247).

> "Control is the ability of the management team to predict, analysed and correct routine operations, in order to optimize three major parameters; quality, schedule and cost, ... In simple terms it is concerned with the detection of deviations of the actual from the planned performance and the correction of such deviations so that the plans can be fullfilled......" (268).

Monitoring is the process of getting the necessary information so that control can be undertaken. Control and monitoring during production process at the site level is undertaken by management personnel. Three separate groups of personnel can be categorized:-

i. The human resources not directly involved in the execution of work on site, but employed by the main contractor.

ii. Personnel employed by the client. Both of these groups are site based, at least for a specific period of time.

iii. Personnel employed by the client, the main contractor, nominated or non-nominated subcontractors, who are not site based.

This classification assumes a traditional structure of contractual set up.

The first two groups can be described as the field management team, because in the non-traditional contractual set up, they work as a team. In the traditional set up, although they may have conflicting priorities and duties, their common aim is to ensure successful completion of the project. It is perhaps better to measure their influence separately. For the purpose of this research, they are regarded as one homogenous resource because of the foreseen problem in measuring their influence separately.

Early studies in productivity have indicated that supervision and team working are essential to the achievement of higher productivity (269, 267, 270). Recently, many researchers have embarked on determining the influence on the production process. Danladi et al (271), found that as the degree of management control increases, construction efficiency increases. This work lacks good quality data but has been further substantiated by Horner et al (235), who found a strong positive relationship between productivity and the degree of management control. Thomas (272) emphasized the need and importance of the number and qualifications of site staff. Horner et al. (235) assumed that the quality of management team was proportional to the value placed on it by the employer and devised a subjective measurement system. This is not important to this research as the influence of control and monitoring can be measured in a more effective way as described below.

Mangement control (273-279), delegation of authority (280); the supervision (259, 281, 282), its quality (269, 267), incompetence (283), ineffectiveness (284, 255) and coordination with gang (285) have been hypothesized to influence productivity. In undertaking control and monitoring, management will be at the work place from time to time. Their functions will vary and their presence at the work place, in supervision, coordination, directing, observing or undertaking other activities will influence productive time. All the above evidence without doubt point to the influence of management team. This will reflect a more direct influence of management control and monitoring on productive time. The influence of the degree of control and monitoring can be measured by the presence of management. Essentially, only the influence of management team at the work place will be examined.

i. THE INFLUENCE OF THE MANAGEMENT TEAM AT

THE WORK PLACE

Onsite casual observations reveal that managerial personnel onsite will visit the work place for the purposes of monitoring and control. Many activities are undertaken by management personnel at the work place. This include supervision of work tasks, measurement of completed work, checking of completed work and testing or setting out.

The time spent out of the site office can be sampled using BRESAAP. Previous studies sampled management presence together with operatives. This has resulted in condensing the actual activities performed by management to a few activities. Notably, every time management is sampled on site carrying out activites not relating to productive or indirect categories, they are categorized under the supervision category. In order to ascertain the influence of management presence, separate activity categories need to be devised so that managerial activities influence on productive time can be examined. Due to practical reasons in the data collection and processing, this vital approach cannot be adopted. Thus information on management activites will be lost. Only two possible ways of measuring their influence are possible: the time spent by management team at the work place or around the site, except at the site office, and the time actually engaged in activites relating to supervision.

Theoretically, it can be assumed that their presence should have positive influence on productive time, because it will induce the operatives to continue working. However, site oberservations indicate that usually the immediate and apparent impact on the productive time of operative will be some interruptions to working due to interactions between the operative and the management personnel. This should be short and random and though a reduction in productive time will occur, it will not significantly reduce the total productive time. The interaction between them is only necessary for certain reasons such as when production process are not according to planned or there is a need to make some contact at the work place. Thus interactions frequently observed could indicate inefficiencies in management, but cannot be ascertain in this research.

High level of management presence at the work place may induce a negative effect by creating resentment. Nevertheless, at a certain acceptable level of management presence, productive time should be enchanced. Empirical evidence from studies reviewed in Chapter 1 indicated that supervision level was on average around 4-6% of total time of operative onsite. In intra site study, this variation is expected to be larger. Hence, the influence on productive time should be easily determined. The need for the presence may not be specifically to induce higher productive time but its causal effect should be so.

The hypothetical relationship is postulated as follows:-

Both the supervision time and the total time management personnel present at the work place will be highly correlated. Both should have a positive influence on productive time provided that management team is efficient and the general motivation of the workforce is positive. The time spent specifically on supervision should have a more greater positive influence because of its more accurate measure. The type of measure to be used for examining the influence will be discussed in chapter 8 and the choice made in Chapter 9.

6.4.3 AD HOC DECISIONS DURING PRODUCTION IN RESOURCE - REALLOCATION, QUALITY, VARIATION AND PRODUCTION METHODS

Management of on-site production as a dynamic entity requires ad hoc decision making to increase efficiency. The influence of the ad hoc decision must also have some bearing upon the productive time. Griffith (286) has asserted that efficient management must be supported with good ad hoc decison making. The influence of ad hoc decisions on productive time at the site level can however be negative. This is because disruption to continuous flow of production will occur when an ad-hoc decision is made as resources may have to be reallocated and work have to be stopped while the decision is awaited. These factors and the need to reorganize production will not always be directly productive.

The influence of ad hoc decisions on productive time cannot be easily estimated. Few empirical measurement of its influence on productivity have been made, although theoretically, it is accepted that decision making will influence productivity. The ad hoc decision influence is random and short lived, but only if the overall management of production is efficient. Otherwise many ad-hoc desicions will need to be taken and disruption to work sequence and consequently productive time will be significant. Thus, although ad hoc decision is essentially a function of good management practice, frequent ad hoc decisions may result in aggregate delay which may significantly reduce productive time. The number of times ad hoc decisions are taken on production can be termed as interferences to the production process. If the interferences to the production process can be examined empirically then the effect of ad hoc decision on productive time can be determined. Interferences to the production process can occur as a result of many factors. Basically only four types of interferences are capable of being measured. These are:-

i. THE INTERFERENCE TO THE CONTINUITY OF TASK/OPERATIONS.

The interference to operation continuity will cause the reallocation of manpower resource to another planned operation and will increase the number of vists (264). Operation continuity from the productive time point of view is important because it will ensure optimum possible working time. Once the decision has been made to discontinue operations, this will influence productive time momentarily. A large number of ad-hoc decisions taken to stop production in this manner will accumulate an unacceptable level of productive time achievement. A high degree of interference to continuity of task/operations will negatively influence productive time.

ii. DESIGN/QUALITY INTERRUPTIONS

Although the sampling will measure the repeat work as part of the activities undertaken, its inclusion as a measure for the design/quality interruptions can be justified. Although repeat work is essentially an activity, the more common cause for this activity is a result of faulty design, changes in design and/or quality. Its measure is therefore a reflection of the influence of design or quality. No attempt is made to place a probability on the influence of each variable. As repeat works reduce productive time, the influence of design/quality will thus be negative.

iii. THE INTERFERENCES TO THE CONTINUITY OF TRADE EMPLOYMENT

The continuity of employment of craft/trade types can also influence productive time, because any prolonged breaks in their employment necessitate pre-planning of task at the work place, hence reducing the productive time. A high degree of interference to continuity of trade employment may also cause a negative influence on productive time.

iv. NEW TRADE INTERRUPTIONS

The interruptions on production can also be felt with the introduction of new operative. Since the influence of an individual trade cannot be measured, the infuence of new craft/trade types to the process will be examined. The new trade/craft type have to familiarize themselves with the site, the task and other factors and this will take time. Although the influence of learning curves may be a better measure (287), such measure is not possible here and the significance of new trade/craft type to productive time achievement should be sufficient for this research. It is postulated that interruptions due to new trade will be negative.

6.5 MANAGEMENT OF DESIGN SUB-SYSTEM

6.5.1 THE DECISION ON DESIGN CHOICE, MATERIALS - SPECIFICATIONS AND STANDARDS OF WORKMANSHIP TAKEN DURING DESIGN AND FEASIBILITY STAGE

Design and materials choice and standards of workmanship decided during feasibility and design stage will influence the ease of production on site. The theoretical models of ILO, Shaddad, and Thomas have noted that design and its associated factors will influence productivity and production time. Thus it will influence productive time. Theoretical assumptions of the influence of design on construction have led to a number of empirical investigations reviewed in Chapter 1. These investigations were based on the premise that buildability is a byproduct of productivity assessment with the focus of attention being on design rationalization (288).

Thomas's factor model placed the design factor above the ideal productivity curve. This can be interpreted that design factors are more difficult to eliminate than other factors. This suggestion is also suported by the theory in ILO's production time model. Its influence on production process is inherent, when decision on design and specifications were made. Thus mistakes or bad decisions at that stage could not be easily rectified and the ideal productivity curve cannot be achieved.

Design factors are also difficult to measure. Buildability as a concept of design influence on production process lacks the proper measurement instrument to test its influence on the various measures of performance. This is supported by Griffith (289) and Bishop (290) where both proposed various approaches in the assessment of the influence of buildability.

i. DESIGN RATIONALIZATION

Design rationalization is a process whereby a piece of discrete elements is designed with four factors being considered. Simplification, standardization, dimensional coordination with fewer and larger tasks for execution (291). The investigations reviewed in Chapter 1 have not shown a great reduction in manhour expenditure (286, 288), although reduction in manhour expenditure on a particular element may occur. The influence of buildability on productive time is also of concern. Data from these investigations show no great variation except for the

Health Centre project, which were accounted for by Griffith (286). From these investigations design rationalization can be conceptualized as influencing productive time.

The notion that design rationalization has not shown any great influence may be misleading, because of the way the data in these studies were interpreted. Thus, although recognising the influence on productivity, and perhaps on productive time, empirical evidence to substantiate this theory is not convincing because of the problems in the methodology of measurement. The variable will have to be investigated, even with a subjective measurement. There will be problem in deciding the measurement scale for design influence and an important assumption has to be made. Since no theoretical argument has been forwarded to suggest a good and effective measure of buildability, it is forwarded that the nature of design of a particular element should be examined. Design of element type with an indication that one or more of the four aspects of design rationalization is incorporated is postulated to have a positive influence on productive time.

6.6 MANPOWER SUB-SYSTEM

The influence of labour on productivity can be distinguished through individual or informal group or unionized group (292). For ease of discussion, the influence of labour on productive time is divided into: the craft/individual influence, the motivational influence and the unionized labour influence. The influence of manpower on productivity has always been investigated from the motivational influence and needs. In order to achieve higher productivity the motivational needs have to be satisfied. The motivational influence is excluded from this research because of the problem of measurement. The influence of manpower on productive time can however, be examined from another angle. These factors include, absenteeism, lateness and idleness, careless workmanship and accidents which according to ILO, are theoretically within the control of the worker (although it is debatable). Absencet, lateness and idleness although measurable directly from BRESAAP are activities rather than the causes. Lim (260) in his model of factors influencing project performance examined the influence of manpower at craft level.

6.6.1 **CRAFT/TRADE INFLUENCE -**

Craft/trade infuence is defined as the influence of manpower as a group and not as an individual. Much work on the influence of group and their associated aspects on productivity have been reported. These include McNally (293) and Parker (281) on absenteesim; Bishop (259) and Causey (255) on efficiency; Woods (394) on attitude; and Parviz (295) on workspace congestion. Adrian (246) has also identified other factors associated with labour that influenced unproductive time. These are high percentage of labour cost, variability of labour productivity, supply and demand characteristics of industry and accidents.

The influence of craft/trade on productive time in this research however, can only be examined in terms of five aspects and these are task interdependence trade, trade variability, the significance of trade, the type of trade and trade duration.

i. TASK INTERDEPEDENCE OF TRADE

The general hypothesis that many construction tasks need the employment of two or three different trades to complete a particular task, necessitating in an increase in the number of visits is perhaps one of the reasons why Bishop (258) proposed that procurement of work in construction should be task orientated. Task orientated work necessitate planning task into smaller work packages which should employ the minimum number of trade types, hence decreasing task interdependence. Gates and Scarpa (296) for example postulated the influence of specialization and subcontracting on productivity indicating that a task orientated structure with specialization and subcontracting should be taken into account in design, planning and execution of task.

Task in construction are thus executed by many types of crafts and this is a common denominator in site production. McNally and Havers (293) and Schroder (297) examined group relationship and the main problem found is that, flow of work will be slowed as result of dependancy on other craft type and essentially reduce productivity. This is due to the interaction between trades during production (258). Interaction due to the non-homogenous trades is expected to be more marked, than interaction between homogenous resources as gang with different trades may have no experience of working together. More time is needed to adjust and adapt to each other's working practices and the necessity of frequent interaction therefore arise. Productive time of a non-homogenous gang may be reduced because of this likelihood. It is postulated that the interaction caused by this will negatively influence productive time.

ii. TRADE VARIABILITY

Manpower allocation to operations need to be well balanced in order to ensure that productive time overall is at an acceptable level. Bishop (259) and Markham (298) have placed empahasis on the size of gangs in planning of the task. This means that gang sizes need to be allocated according to the need of the operation. An unbalanced gang size will lead to idleness in gang, either because of waiting for work or for an extra operartive and subsequently reduce the gang's productive time. Trade variability in task/operations will also negatively influence productive time.

iii. TRADE SIGNIFICANCE

Empirical evidence from Pitcoudie 1 and 2 housebuilding studies discussed in Chapter 1 indicated that a few trades make up a significant proportion of the total operatives time onsite. These trades form between 84-91 percent of the total operatives time. This compares favourably with a figure of 92% of an average distribution of labour content of housing in a study conducted in the late 1940's (269). The influence of the major trades on how time is utilized will thus be considerable, so will their influence on the average manhour achieved for task and operation, and consequently for the whole project. A higher degree of significance is postulated to influence productive time positively.

iv. TRADE TYPE

Site observations confirmed that certain gang types or trade types are allocated work which essentially will reduce their productive time achieved. This is in agreeement with the assumption that skilled worker will do productive work assisted by an unskilled worker undertaking support work. Support work includes preparing, handling, setting out, testing, unloading and cleaning. If trade types are considered, then all trade types should be allocated to roughly the same amount of work type except in cases where special operations will demand high support work, reducing the productive time. Some gangs are also assigned to undertake the repeat work, which again reduces their productive time. In addition, trades within the control of the main contractor are less likely to be productive (299). It is hypothesized that trades within the control of the main contractor will have lower productive time than other trades.

v. TRADE DURATION

It is important that the employment of each trade or gang on the production is prolonged so that the benefits of the learning curve can be realized (287). It is hypothesized that trade or gangs with longer employment time on the project will exhibit higher productive time and thus it will positively influence productive time.

6.7 THE EXTERNAL SUB-SYSTEM

Many theoretical models have included the influence of external factors, which may be controllable or uncontrollable, environmental or non-environmental. It is the environmental aspects which will influence productive time more directly and their presence can be thought of to be independent somewhat of management influence.

The external influences are varied and many. Shaddad (223) summarized the possible influence. Of most concern is the climatic conditions which have a more direct influence on productive time. In manpower dependent production, it has been

> "universally accepted that operations conducted during adverse climatic conditions suffer a loss of productivity - the extent of which depends upon, in part, the type of work and the degree of protection" (300).

The factors in the sphere of climatic conditions include bad weather, air temperature, relative humidity, wind velocity, solar radiation, precipitation and light. It will be impossible to measure all the factors and the selection of relevant parameters associated with climatic conditions have to be examined.

Clapp (301) classified five ways in which weather can influence manhour losses:-

i. Bad weather time, or paid time in which bad weather temporarily prevents craftsmen from working.

ii. Reduced productivity, which occurs when craftsmen continue working, but their output is reduced, thus requiring additional paid manhour time.

iii. Repeat work resulting from damage caused by frost, ice, wind, rain, or the need to correct poor quality workmanship resulting from bad weather.

iv. Stood off time, which includes instances when workers are dismissed, are absent or report late as a result of bad weather.

v. Reduced working scheduled or shortened work weeks that occur during winter months and the result is a loss of momentum.

The influence of the above factors has been further examined in a number of unrelated studies. The National Electrical Contractor's Association (302) for example, reported the effect of temperature on productivity and concluded that productivity rates vary as a function of both temperature and humidity. This study casts doubts on

Clapp's work because Clapp reported inextensive manhour losses as a result of changes in temperature and humidity. Grimm and Wagner (303) found that productivity declined as temperature and relative humidity deviated from 75 Degree F and 60 percent respectively. The gang efficiency could also be as low as 0.50 for very high (100 degrees F) or low temprperatures (35 Degrees F). Compared to NECA study, Grimm reported that relative humidity had a greater effect on productivity. In relation to Clapp's report, Grimm's study probably accounted for productivity loss in the first 3 categories (287). Koehn and Brown (300) conducted a mathematical study on the influence of climatic conditions on productivity, but Thomas (287) criticized their efforts because they used historical data with no knowledge of site conditions or the way in which productivity was measured.

Clapp' classifications (i), (iii) and (iv) should influence productive time. However only classification (i) can be easily measured by BRESAAP. Classifications (iii) and (iv) are measured under different categories such as absent, repeat work etc. but the reasons for these activities are also due to many other factors.

In addition to the effect of adverse temperature and humidity on productivity they should also influence productive time as there is a high probability of production discontinuity when it becomes unbearable for operatives to continue working. The actual time lost due to management decision to stop work due to weather, clapp's classifications (iii) and (iv) and the influence of temperature and humidity need also to be determined and is examined under three specific variables.

i. THE PERIODIC CLASSIFICATION

Seasonal influence (304) on productive time is expected to be of significance and the influence should be cyclic. Cyclic influence can be made to be linearly related by transformation of scale of measurement or re scaling. However, due to the problem of an apprrpriate measuring instrument, only the periodic influence will be examined, by classifying the variable into monthly or quarterly according to the extent of its influence on productive time.

ii. WEEKLY WEATHER INFLUENCE

It is also possible to create an index of weather variation on a particular project. An index with perhaps a nine point scale could be constructed and it is postulated that a higher index which measure high variation in weekly weather changes will influence productive time negatively.

iii. BAD WEATHER INFLEUNCE

It is expected that manhour loss due to bad weather will be marked in winter months and when the building is not yet enclosed. However, it should be interesting to find out the variation that can be accounted for from weather loss in the analysis. This variable will thus have a negative influence.

6.8 THE SITE SUB-SYSTEM

Job location (285,294), site congestion, access and layout (232,233) have been identified influencing productivity. These are the site factors. Of the more important factors in this category suitable to be investigated for intra site studies are easy access to work place, site layout with respect to material and plants location and storage and location of operation. Only the floor level can be examined in this research.

i. THE FLOOR LEVEL

The floor level influence on productive time has never been examined. Material storage, plants location and preparation area are parameters associated with good site planning. If material storage and preparation area are far from the work place, the increase in travel time will subsequently decrease productive time. In addition most of these parameters are also located at ground floor and thus it is expected that productive time at ground floor will be lower than at the upper floor.

6.9 PRODUCTIVE TIME ATTRIBUTES

The left hand side of figure 6.2 shows the attributes of productive time which can be used to examine their influence. These are the tasks attributes, the manpower attributes and the periodic attributes. The task attributes will have two types of measure, the operation and the building element, while the manpower attributes will have the craft and gangs measure. The periodic attributes can have daily, weekly or monthly measures. However as most production control and monitoring is usually done weekly and because of the problem in generating output on a daily basis, only the weekly measure will be considered. Therefore, there are five separate theoretical models of atrributes of productive time where the influence of these factors needs to be examined. Figure 6.3 summarizes the type of theoretical model and the postulated relationships to be examined. For ease of discussion, the influence of each of the factors on each model will be examined in Chapter 8, which also describes the transformation of data into relevant variables and the unit of measurement used.

FIGURE 6.3
SUMMARY OF THEORETICAL MODELS

THEORETICAL MODEL A - WEEKLY PRODUCTIVE TIME

$$Ap = a - x1 - x12 - x14 - x7 - x9 - x16 - x17 - x18 + x19 + x5$$

THEORETICAL MODEL B - CRAFT PRODUCTIVE TIME

$$Bp = a - x1 - x14 + x15 + x13 - x7 - x8 - x18 + x19$$

THEORETICAL MODEL C - ELEMENT PRODUCTIVE TIME

$$Cp = a - x1 + x3 + x2 - x4 - x12 - x14 - x7 - x6 + x10 + x19 + x5$$

THEORETICAL MODEL D - OPERATIONS PRODUCTIVE TIME

$$Dp = a + x5 + x3 - x4 + x2 - x12 - x14 - x7 - x6 + x10 + x19$$

THEORETICAL MODEL E - GANGS PRODUCTIVE TIME

$$Ep = a + x5 - x1 - x4 - x14 + x15 + x13 - x7 - x8 - x11 + x19$$

WHERE

x1=TASK/OPERATIONS VARIABILITY (-ve)
x2=TASK/OPERATIONS SIGNIFICANCE (+ve)
x3=TASK/OPERATIONS CONTINUITY (+ve)
x4=TASK/OPERATIONS TYPE (-ve)
x5=MANAGEMENT TEAM INFLUENCE AT THE WORK PLACE (+ve)
x6=INTERFERENCE TO THE CONTINUITY OF TASK/OPERATIONS(-ve)
x7=DESIGN/QUALITY INTERRUPTIONS (-ve)
x8=INTERFERENCE TO THE CONTINUITY OF TRADE EMPLOYMENT(-ve
x9=NEW TRADE INTERRUPTIONS (-ve)
x10=RATIONALIZED DESIGN TYPE
x11=TASK INTERDEPEDENCE OF TRADE (-ve)
x12=TRADE VARIABILITY (-ve)
x13=TRADE SIGNIFICANCE (+ve)
x14=TRADE TYPE (-ve)
x15=TRADE DURATION
x16=SEASONAL INFLUENCE (-ve)
x17=WEEKLY WEATHER INFLUENCE (-ve)
x18=BAD WEATHER INFLUENCE (-ve)
x19=WORK PLACE LOCATION FACTOR (+ve)

CHAPTER SEVEN

CHAPTER SEVEN

7 FIELD STUDY - DESIGN, MEASUREMENT AND EVALUATION

7.1 OVERVIEW

The design of the BRESAAP classification system will depend on the following:-

i. The type of building work to be monitored.

ii. The information required.

iii. The capabilities of BRESAAP to handle classification system and information.

The choice of building to be monitored is very restricted. The only available building is a proposed academic building which is to cater for staff offices, drawing offices, laboratories and lecture rooms. This building is three stories high and will provide accommodation and circulation space of approximately 4420 metre square. Figure 7.1 shows the three-dimensional perspective of the proposed building.

At the commencement of the field work, production monitoring using BRESAAP at the site was already in progress for five months. The data collection is a continuation of an investigation on the influence of buildability and productivity measured in terms of manhours expenditure. This was briefly reported by Griffith and Barron (305) but the monitoring was abandoned due to difficulties not concerned with this research. This was a good opportunity because of the potential that could be

FIGURE 7.1

Three-dimensional Perspective Of The Proposed Building

realized from the use of BRESAAP data. The difficulty of getting cooperation especially on matters relating to daily management of site, in addition to site availability problem lead to the decision of continuing the data collection but with a different objective.

7.2 DESIGN OF DATA COLLECTION SYSTEM

The data collection system had thus been designed and the procedures for implementation had also been decided. There was an option of abandoning the original design of the data collection and the procedure and use a new one. This will satisfy the research requirement. The second option was to use the same procedure as well as using the collected data in the final analysis but sacrificing some other information.

An indepth analysis of the research requirement confirmed that in general what was needed and what was thought to be capable of being accommodated by BRESAAP had already been included in the design of the data collection procedure. Although further classifications need to be done, the existing design would suffice.

More significantly the earlier data will provide more information for the database for analysis and validating the hypothetical model for onsite production which should cover the whole of construction work. Another important factor that was not realized until towards the end of this research was that a new design of data collection system and procedure would necessarily mean changing the algorithm of BRESAAP. The idea was thought of but was again abandoned because BRESAAP was originally on PRIME system. When BRESAAP was transferred to the VAX system no proper manual was published necessitating the help from BRE which was not easily available.

Consequently, the data collection continued based on the classification and coding system of collecting information which had been previously designed. A thorough examination of the data collection procedure and design at that particular time satisfies the research requirement that within the practical limits of any research, the design of the data collection procedure will not necessitate any major modifications. Among the modifications that were supposed to be made but were never undertaken are as follows :-

i. The addition of extra activities for the management team, so that their influence can be examined in much more detail.

ii. Additional location numbers for upper floors because the design for work place location on the OMR sheet was not sufficient.

The structure of the classification system of BRESAAP has already been described in Chapter 4. The relevant classifications based on this structure consists of classification of manpower resources, management team, location of work, work classification and activity lists.

i. OPERATIVES AND MANAGEMENT TEAM CODING

Appendix A.1 illustrates that each trade type is allocated a block of numbers. Up to four levels of classification are given, these are individual operatives number, trade group and status of operatives. An identification number is also assigned to management team personnel.

ii. WORKPLACE LOCATIONS

The building is divided into areas. Previously its use had been to simplify the monitoring exercise. Appendix A.2 details the location areas. Due to the problems with the design of the OMR form, BRESAAP cannot accommodate more than location number 79. This initially was a constraint in the data collection. It was realized later that if the obervations were coded and separated in separate floors, then the possibility of investigating the influence of floor level might be available.

iii. WORK TASK CODING

The coding already exist for the original design was a two part coding which defined the stages of work into 'building element' and 'operation'. Appendix A.3 lists the classification. It should be noted that the specific tasks at each work place can be identified, if data regarding operation and location can be tabulated with dates being in the third dimension.

iv. ACTIVITY CATEGORIES

The activity categories are listed and defined in the Appendix A.4.

The 'F1' activities are generally termed as the productive activities while the rest are divided among the unproductive and the indirectly productive categories. Productive category can be narrowly or broadly defined. For example if productive time is to be broadly defined, categories 'P1', 'H2' and 'T1' can be included to be productive. Nonetheless not all activities of 'P1', for example, will be necessary for the work. Thus including 'P1','H2' and 'T1' categories for a broader definition of productive time may not always be valid.

7.3 ISSUES OF VALIDITY AND RELIABILITY

Validity and reliability in social research is generally regarded as a fundamental problem of theory. According to Kirk et al. (306), theoretical validity should be discussed in terms of apparent and instrumental validity. Apparent validity is 'face validity', the obviousness of the relationship between an observational procedure and what it is intended to observe. Instrument validity (pragmatic or criterion), exist in a measurement procedure, such as activity sampling. If it can be shown that observations can match those generated by an alternative procedure that in itself can be accepted as instrument validity. Kirk (306) proposed that if instrumental validity can be proved, the apparent validity need not be considered. Thus theoretical validity could be justified by instrumental validity. Quantitative research methods have emphasized the issue of reliability, which checks the strength of the data. Kirk view that in social science research, the aspects of 'reading the field' should incorporate the checking of validity and reliability.

Validity in Heiland's et al. (307) viewpoint refers to the data which should meet the test of agreement with other reliable measure. This measure may form part of the information gathering and should correlate with the study. They emphasized that the

> "evaluation of validity is really an evaluation of the entire process of gathering and recording the basic data".

They quoted three components which are seen as necessary to evaluate validity.

i. Alertness and objectivity.

ii. Familiarity with and understanding of the principles and techniques of statistics.

iii. A complete record of conditions surrounding the taking of observations including measures of production.

While on reliability, Hieland et al. referred to it from the statistical viewpoint.

7.3.1 ACTIVITY SAMPLING'S VALIDITY

Both the above views are sufficient to ensure the validity of BRESAAP used in this research. The issue of validity needs to be adressed to include the whole data collection methodology. It must be evaluated in terms of the basic fundamental theory, the reliability of data, observational and procedural validity. Instrumental validity of the technique can only be compared against continuous observations of the same sample. Results of different sample cannot usually generate comparable results. On the other hand, the impracticality of continuous observations meant that activity sampling technique cannot be validated by the comparative approach with continuous observation. Apparent validity is a very subjective issue in reference to sampling the activity of manpower as there will be variation in activities performed. The pattern of time utilized daily, weekly, operation to operation, project to project and between operatives will vary and eventually the results cannot be validated from apparent validity. Theoretical validity using apparent validity is therefore impossible to achieve for BRESAAP because data is only the best approximation of the exact situation.

7.4 VALIDITY OF DATA COLLECTION METHODOLOGY

Reliability of data is perhaps an alternative way of validating the data collection methodology. The reliability of the data however, can only validate the methodology partially, other issue need to be considered to make the technique more valid. It is proposed here that the validity of BRESAAP is examined and evaluated from the following points:-

i. Evaluation of reliability

ii. Evaluation of observational validity

iii. Evaluation of procedural validity

Methodological validity therefore involves satisfying the above three criterias. Reliability or strength of data is from the statistical viewpoint, which should form the prime cosideration in any validity evaluation. Observational validity is concerned with validity of observation and statistical principles cannot be applied. Error in observation cannot be measured except in clerical error. The over-reliance on the observer to achieve higher observational validity demands a thorough understanding of the sources of error which can reduce the validity. This will be the best means to enhance observational validity. Procedural validity relates to the way BRESAAP is applied on the study. Whether the proposed procedure is valid is again subjected to a number of considerations and no ultimate measure for this criteria has been developed.

7.4.1 EVALUATION OF STATISTICAL RELIABILITY -

The issue of statistical reliability has been partly discussed in Chapter 5 when the problem of examining the data was examined. The adoption of Generalized Linear Modelling technique which is able to measure and include the statistical error in the analysis for the purpose of determining the influence of factors on the response variable has been discussed. This essentially mean that the whole problem of statistical reliability can now be regarded as partially solved. Previously statistical reliability was greatly emphasized in order to enable data to be analysed which necessitate a certain limit of accuracy to be achieved. The limit of confidence or the limit of the statistical error which can be allowed to be present before data can be valid is an important consideration of any activity sampling study. With the use of GLM and binomial distribution, the reliance on normality in data, which is the basis of statistical error calculation can be disregarded.

For the purpose of increasing the statistical reliability for each set of data point, the number of observations per case in attributes of productive time have to be maximized. There is practically no way this can be achieved. Statistical reliability can be determined by the number of observations made, the chance of an activity being observed and the limit of accuracy which is acceptable. When using normal distribution assumption, the limit of confidence of around 95 percent or 2 standard deviation is always aimed for and considered as acceptable. The limit of confidence refers to activity (p). The chance of an activity happening cannot be guaranteed, hence the accuracy can only be determined when the study is completed. In general, 400 observations on an object with the p being 50 percent will yield an accuracy of +/- 5 percent. This general rule can only be an approximate guide. Consequently the evaluation of statistical reliability in this way defeats the purpose of an activity sampling study because of over-reliance on statistical accuracy. Using Generalized Linear Modelling, the statistical accuracy and the error is already considered with the binomial denominator or the total number of observations included in the modelling. It is then considered immaterial to prolonged the discussion on statistical accuracy. The more important consideration is the randomness of observation which will be discussed later.

7.4.2 **OBSERVATIONAL VALIDITY -**

No accepted measure of the validity of an observation by an observer has been formulated. Usually ways to enhance the validity are proposed and this must be the weaker point of the methodology. Increasing observational validity will reduce the subjectivity and is paramount to increase the quality of data produced. The sources of error have been noted by some writers: the problem is not only in the determination of the magnitude of the error present in the observation, but also because it is not predictable. Observations may contain some form of observational error, unmeasurable unlike the statistical error. The identification of the sources of error and taking steps to reduce the circumstances is the best solution available. Six sources of error are identified below:-

i. HUMAN LIMITATIONS

Inability of observer to cover all assigned areas uniformly and the ability of identifying all detail activity on the project is a problem. Greater demands on observer's ability is placed when classification becomes more complex. Although this eventually will generate more information, it nevertheless require highly skilled observer to determine the exact nature of work at a 'snap' moment (308).

ii. VARIATION BETWEEN OBSERVERS

"All observers will not interpret identical events in an identical manner"(308),

and this factor is more difficult to determine because the degree of differences between observers which depends on the experience and knowledge of site production. A clearly defined frame of reference in the classification system and the definitions of proper terms which are used will to a degree, reduce the differences between observers.

iii.OBSERVER'S BIAS

The pre-judgement of operatives behaviour must be avoided, especially if the observer is part of management team. This usually leads to the observer having a pre-conceived opinion of their operatives (308). When this bias is present, a less concerted effort will probably be made to correctly record the observations, especially if the objective of the study is to prove significant idleness on site. The introduction of this bias may be more serious than the problem of randomness in observation.

iv. OBSERVER'S FATIGUE

The whole exercise through experience can be fatiguing and boring, especially when the data cannot be processed and the feedback is not made during the monitoring period. As an example Pitcoudie 1 and 2 reviewed earlier employed two observers for 101 weeks, undertaking observations at two hourly interval each. Although the data is statistically reliable, the reliability of the observations has to be questioned. Fatigue will be a source of error when an observer is placed for a long period, undertaking monotonous work. The reduction in the number of rounds that has to be made by an observer may perhaps reduce this problem. This problem has been felt in the study, even though only two rounds are made per day, with one observer for the first quarter of the study and another for the rest of the study period.

v. WHEN TO 'SNAP'

Determining when to snap is another source of biasedness. The activity recorded at a particular instance has been observed in this study to vary in a matter of seconds. This may result in recording the next activity instead of the previous one. How long should a snap be allowed to take place, is a problem which may lead to snap bias. The term 'at an instance' may be easily put forward but not easily adhered to. Time-lapse photography techniques can easily achieve this but its principle cannot be adopted easily to the human viewfinder, because 'snapping' a state of condition of an object is not recorded permanently in human memory such that this bias can never be eliminated.

vi. ABNORMAL WORKER BEHAVIOUR

This problem is centred around the earlier assumptions of work study of hostile reactions from workers who resent any action by management to force a change in their own work habits (309). As a result this can induce a change of behaviour (308). The earlier solution is to undertake work study in absolute secrecy, although Taylor was quoted as having disassociated himself from this (309). Barnes (310) emphasized that a proper relationship between observer and the operatives is paramount, to reduce the effect. This however may be difficult to establish, especially when deep rooted resentment against any form of work study is assumed to be present.

Various suggestions have been made, including setting of a control group (339), to overcome this. The observer must be also aware of the effect of the classic Hawthorne Study. Control groups in building production cannot easily be made because building operations change in the nature of production and work place form time to time. Unless evidence can be found that the performance of two groups under dissimilar conditions of operations and work place do not vary much, the use of a control group may complicate matter further.

The presence of an outsider as an observer or an expert is a also problem: not only because of the industrial relation problem which may arise but also because he is often denied the truth (311) until he can find out for himself. The current recommendation by BRESAAP (312), is to introduce the observer at the earliest possible stage in the construction period. The hostility or abnormality may persist in the beginning, but after a long time on the site, the observer will be accepted as part of the group as experienced in this research. The observer must also try to 'snap' the operative when he is not aware he is being observed. This is important and an obeserver must be able to draw a firm line beween 'acting' to perform task and actual activities by the operatives under observation. As the data collection lasted for a period of 82 weeks, this effect can be largely reduced. The effect in a shorter period of monitoring could be more significant.

The problem in observational validity, may then be regarded as relying on the observer's understanding of the above sources of error, unlike statistical reliability which can be confidently estimated and the significance of each attribute considered. Perhaps a ranking of these problems by work study practitioners or those involved with observing and recording men at work would help an observer in placing more attention to the more significant source of errors in observation. The understanding of this problems and taking action to reduce it will be the best solution at the moment. These problems do not invalidate the observations in this study as the main aim is to observe productive activity and recording other attributes associated with it. The other attributes can easily be determined and the examination of a two activity situtation will ensure more valid observation. It will be easier to determine productive and non-productive activity instead of classifying activities into more than 15 categories.

7.4.3 **PROCEDURAL VALIDITY AND PROBLEMS -**

The adopted procedure and the problems associated with it is another validity consideration. The satisfaction and arguments for the procedure adopted for this research will enhance the procedural validity.

i. OBSERVATION ROUNDS

Section 7.4.1 has noted that the number of observation rounds will be the prime factor in determining the number of observations and hence the statitical reliability. The last section noted the problem with continuous onsite monitoring which may result in fatigue and snap bias. To reduce this the number of rounds per day needs to be reduced. The question is whether the reduction will invalidate the procedure. BRESAAP allows time interval of five minutes to a four hourly. The four hourly or two observations round per day was adopted. This will reduce the problem in observational validity but at the same time will not invalidate the procedure, as the majority of operation/task and not activity will lasts for more than an hour. From site observations it was even safe to assume that most operations/task take half a day period to accomplish. The frequently missed operation is concreting, and this is only at a particular location and not the whole of the task. Hence the BRE suggestion has not been wrongly adopted.

Continuous monitoring is required to determine the actual pattern of the time utilization time. In defiance of this, it has been decided that the best solution is to seek the least number of rounds, although the actual time utilization will never be known. The acceptance of the concept of sampling will uphold the argument. In sampling this must be considered in terms of the 'whole' population which will be sampled (307). As the duration of the study is prolonged, the lesser observation round is a valid parameter eventhough it is a fact that some minor operation has been missed. It is also true, that the actual pattern of activity for a particular day cannot be determined but this is not the objective of this research. The validity of the procedure can still be achieved in terms of acquiring the data of time utilization for the duration of the construction phase.

ii. RANDOMNESS

The randomness of activity sampling must be maintained, as it may lead to judgement sampling which is another method of collecting data from populations (309). If the randomness is not maintained the risk of random bias may eventually invalidate the basis of sampling. The randomness of observations must be differentiated from the number of observation rounds. The latter refers to the number per day, whilst the former refers to the timing of observations during that particular period. Randomness also refers to the timing of observations and not the randomness of the activity of the object, since activity state of an object always differs from time to time, random timing will ensure an unbiased result.

Although the majority of opinions acknowledge that the nature of construction operation varies, it has been emphasized (312) that randomness may not be too important in activity sampling unless the work is of a cyclic nature which necessitate extreme care in deciding the timing of observations. Whether or not randomness must be a prime consideration, only a full site trial on the same operation at that same location for the same project and if possible by the same observer should be made. The variation in the result where the only difference is the timing of such observation could strengthen the argument for or against randomness.

Although there are risks in not ensuring randomness (313), the extent of such risks are thought to be minimal. As a precaution the timing of observations made in this study excludes the break time and lunch time to avoid break activity being snapped. The varying nature of site process, its activites and changing work place has been observed and it is noted that most operations are not cyclic, such that less emphasis can be made on the timing of observation. The timing of observation in this research has been made as short as the first observation has finished or as a long as the working days allows.

iii. CREW VERSUS TOUR APPROACH

This research uses the tour approach, while a crew approach (314) has not been chosen for several reasons. It is important to note that the crew approach was suggested as a more effective way to provide management with more information. Thomas (314) noted that on large project, there are a variety of activities taking place, some of which may not be critical to the timing of the schedule of work. Concentration of sampling on critical item of activities on the schedule will mean that any problems pertaining to the scheduled target may rectified. The problem of keeping track of large number of crews in the tour approach will be reduced using the crew approach. The problems of crew acceptance may be more prominent in the crew approach, although Thomas argued that in his experience this approach resulted in the improved understanding between the observer and crew. In using the tour approach for this study, the observer is accepted into the group by frequent informal contact outside the observation round in addition to the prolonged period of study. Both approaches have their advantages and the issue of crew acceptance must not be regarded as the only determinant in the choice of either approach. Instead the need of the study must be examined.

The crew approach is not suitable to meet the objective of this research as more observer would be needed. If only one observer is used, the time utilization of manpower not involved in the critical activities may not be known. Although their inefficient time utilization may not be criticial to the scheduled target, their time is still paid and thus the monitoring of their time must also be made. It is clear therefore that the choice of the approach must be compatible with the objectives of the study.

iv. DEFINING THE POPULATION

The sample in this study is taken to be all operatives observed on the site for a particular day. On large congested site however, observations of all operatives at a particular time is difficult. Hence, the tour approach, should be designed to cover the observation round as fast as possible. BRESAAP allows a five minute gap in the recording into the OMR forms, which means the exact timing of the 'snap' is not important to be precisely recorded. In this study the start of the tour is taken as the time of the snap and the round usually lasted for ten minutes. Operatives who are always on the move usually create a recording problem when in one observation round he may be snapped twice. This means a decision has to be made on which snap the recording is to be made. The problem of cross-over of operatives form one work area to another was overcome by recording the operative when he was first observed.

v. ACTIVITY CATEGORIES

The recording of information and possible classification of the number of activities is vast. The way it is classified also varies form one study to another. Much concern has been voiced on the maximum classification which is allowed because no set of rules exists which can be followed. The prime consideration is perhaps whether the observer is affected with a larger choice of selection of categories. The argument against having more activity categories is valid due to the problem of determining many activity categories. The observation of productive activity only as a prime measure enables the criticism to be avoided and enhancing the validity.

7.5 DATA COLLECTION

Building works started in late Jun 1985 and were completed in April 1987. The site was monitored up to week 82 of the contract. It is estimated a total of about 10 weeks at the end of the contract was not monitored. Two employed, the first one was on site up to week 20 and the second from week 21 to week 82. The contract was actually delayed, the completion time was revised from the original Christmas 86 target to about April 1987 when actual site work stopped leaving only necessary operative until the date of practical completion which was in June 1987.

7.5.1 INTERRUPTIONS

The monitoring was interrupted by public holidays, when the site was closed (5 weeks), personal holidays (1 week), and weeks when less than ten observations are made because of public holidays or because only one observation was made in one day of the corresponding week. A total of 76 weeks of actual observations were made and is summarized in figure 7.2.

7.5.2 NUMBER OF OBSERVATIONS

The number of operatives range from 30 to 60 on any day. An average of 40 is used to determine the number of observations. Therefore, the total number of observations is estimated at 30,000 which would be sufficiently large to provide a relatively high accuracy. The actual number of observations made during the 76 weeks of monitoring were 24,800.

FIGURE 7.2

SITE OBSERVATIONS

	no obsrvn.	obsrvn.
Observer 1 :		20 weeks
Observer 2		
complete weeks :		51 weeks
incomplete weeks:		5 weeks
holidays :	6 weeks	
Total	6 weeks	76 weeks

7.5.3 ADDITIONAL RECORDING

For the purpose of providing a descriptive record of the monitoring, a site diary was used and the procedure and sample form are in Appendix A.5. Its use has been made in previous housebuilding studies. Its main use in this research was in the creation of weekly weather index which will be described in the next chapter.

7.5.4 END OF THE STUDY

The study was completed in January 1987 although the contract period was extended to around April 1987. The whole construction period was not monitored as minor and irritating problems especially associated with snagging work surfaced towards the end of the contract period. It was observed these problems affect the motivation of many operatives. To avoid aggrevating these problems, the study was terminated earlier. This however dodnot mean that the study itself was plagued with problem but in the interest of all concerned, the presence of the observer should not be part of the whole problem facing the project. Although valuable data could have been lost after the study, this was unavoidable. It was estimated that the about 1,800 observations were not recorded since the study was terminated earlier.

CHAPTER EIGHT

CHAPTER EIGHT

8 DATABASE: PROCESSING, OUTPUT, TRANSFORMATION AND RETRIEVAL

8.1 INTRODUCTION

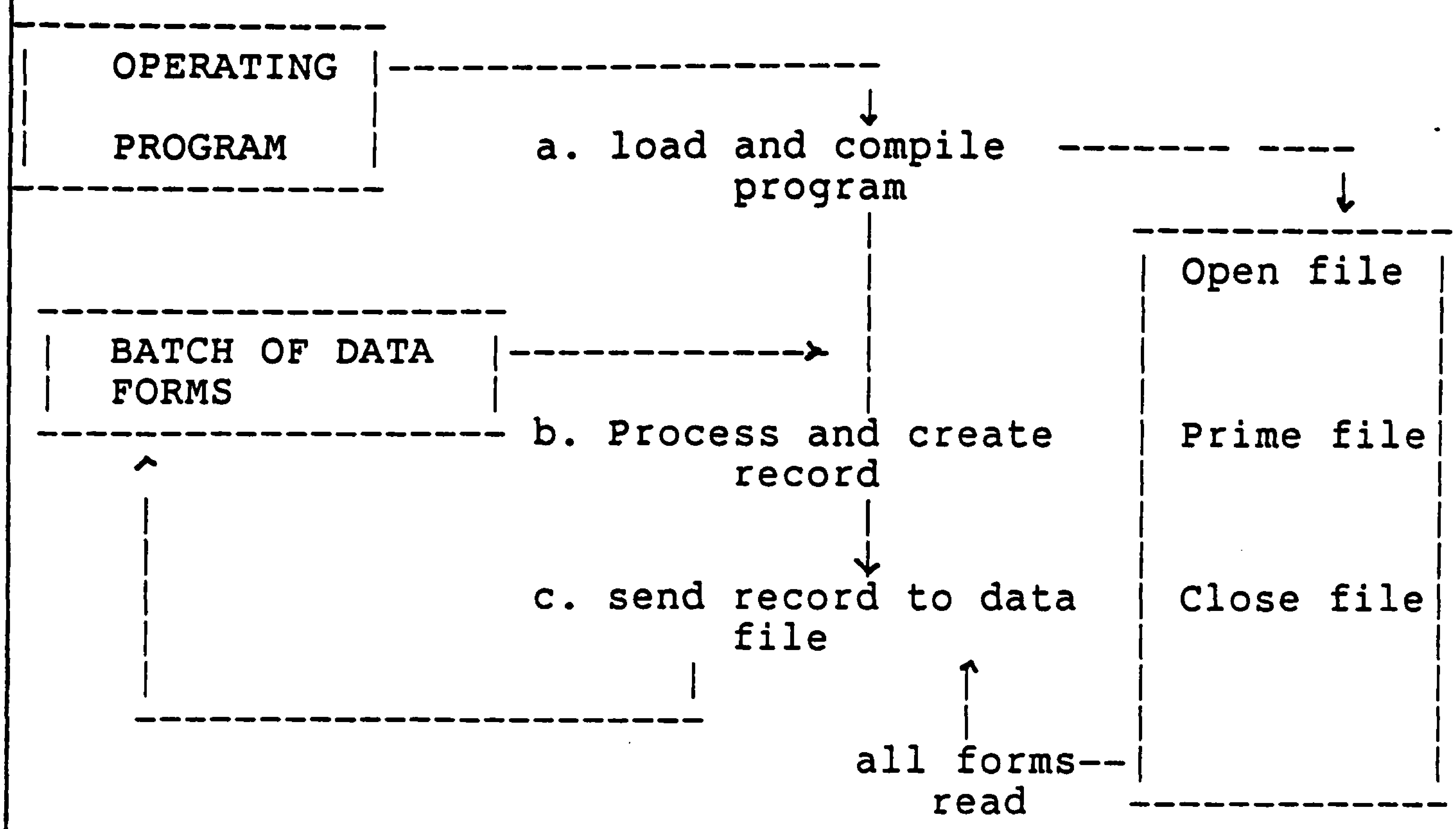
This chapter will describe the processes involved in the use of the observed data to yield information relating to the productive time and the conceptualized variables. Four main processes are involved: the data processing; data output; data transformation and data retrieval. Data processing and output utilize current BRESAAP facilities while data transformation and retrieval are done without the aid of any computer system. The main reason for undertaking manual process for the two later processes have been dealt with in Chapters 4, 5 and 7.

8.2 DATABASE PROCESSING

The completed OMR forms are separated into three batches: the ground floor; first floor; second floor and roof level and the reason for this has also been explained in Chapter 7. All the OMR (Optical Mark Reader) forms are manually checked before they are processed. The processing was undertaken four months after the study was completed and it covered the period from June 1987 to April 1988.

FIGURE 8.1

THE SET OF ACTIONS WHEN READING BATCH OF OMR FORMS



The data processing was done in two stages:-

i. Data input into the database

ii.Data checking and editing

8.2.1 DATA INPUT INTO THE DATABASE -

For each batch of the OMR forms, the Optical Mark Reader transcribed the information on the forms after it has been fed by hand into the OMR. The stages involve in using the OMR and the Prime computer system in the Defects Sheets processing by the BRE(336), has a similar process to the reading of the data for the OMR sheets used in this study. The reader contains 16K micro and its own internal operating system but because it contains only limited storage space, the program has to be compiled from the Prime system so that it can read the forms when it is fed by hand. The reader then transcribes the information on each form as it is reading according to a purpose written program and creates a single 96 character record of its content. This record is automatically displayed on a VDU (visual display unit) which is connected to the OMR and is copied to a previously opened file on the prime computer. Figure 8.1 indicates the set of actions for reading a batch of forms and copying the contents to a named file on the prime system.

A total of 17,665 observations for the ground floor, 4,154 for the first floor and 3,671 for the second floor were read and reside in several raw data files in the Prime system. This therefore means that there are 25,490 observations which were made during the study.

8.2.2 DATA CHECKING AND EDITING -

This is the second stage in data processing. During the input of the forms to the OMR, any missing observations or attributes are checked and noted for the purpose of editing the transferred file. The checking and editing of the file is done on the editor of the VAX system after the data is transferred from the Prime to the VAX system. All the correction of missing attributes are made by checking the OMR forms. Most of these errors occur because the reader failed to read the information on the forms due to bad marking. These errors are small and are corrected and do not in anyway invalidate significantly the observations made.

8.3 DATA OUTPUT

The output that is needed for the later processes are obtained by creating several more data files. These are:-

i. Workforce file.

This is the information on all the workforce and management team observed and recorded during the study.

ii. Site description File.

This is the information relating to the site, element and operation classification.

iii. Batch round time file.

This is the information on the timing of the observation for each day of the study.

TABLE 8.1

LIST OF OUTPUT OBTAINED FROM BRESAAP

NAME FOR TABLE	GROUND (S59OUT-TB.?)	FIRST (S60OUT-TB.?)	SECOND (S61OUT-TB.?)
1. STAGE V. TECHNIQUE	T01	T01	T01
2. STAGE/OPERATION V. TECHNIQUE	T02	T02	T02
3. TRADE V. TECHNIQUE	T03	T03	T03
4. STAGE/OPERATION V. TRADE	T04	T04	T04
5. STAGE/TRADE V. TECHNIQUE	T07	T07	T07
6. DATE V. TECHNIQUE	T08 T09	T08	T08
7. DATE V TRADE	T10 T11	T10	T10
8. STAGE/DATE V. OPERATION	T12 T13	T12 T13	T12 T13
9. STAGE/DATE V. TRADE	T14 T15	T14	T14

The workforce, site description and batch round time are information needed to generate output from observed data using BRESAAP. A simple program instructing the package to generate output is then created. Table 8.1 lists all the output generated. However the following should be noted when examining the data:-

i. Daily productive time output is not avaliable as an option. This is another setback and in agreement with Thomas (316), who stressed the importance of daily productive time as the best means of measuring the influence of variables. The next option of weekly productive time is available but this will reduce the number of possible data points by a fifth.

ii. The output is restricted to three dimensional while some output for example, the productive time of each gang on an operation is not available because the algorithm in BRESAAP does not allow the relationship to be retrieved.

iii. Data processing by BRESAAP does not include some unproductive activities in its output specific to a particular element or operation, although in essence the unproductive activities can sometimes be associated with a particular element or operation. Therefore, the level of productive time achieved for theoretical model A and B level will be lower than the productive time for other models. Nonetheless, this will not necessarily pose a major problem since the percentage is not used as the measure of productive time. This means some variables cannot be associated with some models because of the restrictions. For example if BRESAAP allows the activities of walking (W) to be related to an element or operation, it will reduce its productive time because the total number of observation associated with the element or operation will be increased. Since this is not so, redundancy in the observed data exists. An examination of each output tabulation will reveal that this infomation are recorded at the beginning of each output representing some redundancy in the observed data.

8.4 DATABASE TRANSFORMATION AND RETRIEVAL

Database transformation and retrieval is done after all the output has been obtained from the processes described. The transformation process will describe in detail how the data from the output of BRESAAP can be transformed into factors influencing productive time. Each source of data from which the variables are obtained will be explained. The unit of measurement for each variable will also be discussed including the problems faced in the choice of suitable measure for a particular variable. Data retrieval is the process of retrieving the data and subsequent input into data files in the VAX system to be analysed by GENSTAT.

8.5 VARIABLES TRANSFORMATION - CONSIDERATIONS

The analysis regarding manpower productive time at the site level can be done in various ways using the theoretical models which postulate the influence of certain variables on manpower productive time. There are two main ways of analysing the influence of variables on productive time at the site level. At the more general level, productive time for the whole site will be of interest because the influence of external variables will be more marked. At a more detailed level productive time at the work place or crew level can be examined. The latter analysis will be more concentrated on the productive time of various gangs or operations. In relation to site level productive time the daily, weekly or monthly productive time can be obtained. While at the crew level output tabulations on element, trade, gang and operation could also be obtained.

The way the data has been collected and the capability of BRESAAP to produce output required to transform into certain variables has somewhat restricted the actual analysis required. The restrictions on the database output meant that the variables influencing productive time in the various theoretical models may be different. The consequence of this will be that different variables will be influencing the different analysis differently and some care has to be taken in drawing conclusions from this study.

TABLE 8.2 - TRANSFORMATION OF VARIABLES

-SOURCES OF OUTPUT TABULATIONS

VAR.	THM A	THM B	THM C	THM D	THM E
		TABLE	(refer to table 8.1)		
NP	8&9	3	1	2	7
NT	8&9	3	1	2	7
X1	12&13	4	4		4
X2			1	1	
X3			12&13	12&13	
X4			1	2	7
X5				2	ME/4
	SL/8&9		1		MH/4
	MH/10&11		4		MW/14
X6			12&13	12&13	
X7	8&9	3	1	2	7
X8		10&11			14
X9	14&15		SD	SD	
X10					
X11					4
X12					
	10&11		4	4	7
X13		3			7
X14	10&11	3	4	14	14
X15		10&11			
X16	SD				
X17	SD				
X18	8&9	3			
X19	8&9	3	1	2	7

8.6 THE PRODUCTIVE OBSERVATIONS AND THE TOTAL NUMBER OF OBSERVATIONS

BRESAAP measures productive time in manhours and not productive observations as required for analysis using Generalized Linear Model with binomial distribution. This will necessitate the reprocessing of data from output tabulations of BRESAAP because the output is in percentages or manhours. Observation round in the study was done twice a day, representing approximately four worked hours per observations. BRESAAP calculates the interval between observations to determine the actual hours an observation represents. Reprocessing the data means that the number of observations is divided by the appropriate observations interval. Some division of manhours from output tabulations however, do not equal to the exact number of observations because some interval between observations are not exactly four hours and thus the number of observations are rounded to the nearest whole number. This is unfortunate and was not foreseen at the beginning of the study. It nonetheless still gives an approximation to the number of observations. Accuracy has to be sacrificed in order to adopt a correct principle.

The total number of observations (NT) and the number of observations productive (NP) need to be extracted from the output tabulations. Table 8.2 lists the sources from which the data for NP and NT for each model is obtained. The data are then transferred into data files which will contain other variables to be transferred and described in the respective sections of this chapter. In some output the total hours obtained include the time taken by management presence because management was sampled together with operatives for ease of processing data using BRESAAP. A reduction in the actual observed hours for operatives from the total hours in the repective tables has to be made. Most of the data are transferred after the deduction and the reduction into actual observation are made during the analysis.

Note: Actual observed working hours is defined by the total hours at the margin of output tabulations from BRESAAP deducting manhours taken up by management, if any.

8.7 THEORETICAL MODEL A -WEEKLY PRODUCTIVE TIME

The model will consists of productive time data grouped into week. The weekly productive time is hypothesized to be influenced by 10 variables capable of being transformed and measured. The postulation of the relationship is in the formula:-

$$Ap = a - x1 - x12 - x14 - x7 - x9 - x16 - x17 - x18 + x19 + x5$$

where:-

x1 = TASK/OPERATIONS VARIABILITY

x5 = MANAGEMENT TEAM INFLUENCE AT WORK PLACE

x7 = DESIGN/QUALITY INTERRUPTIONS

x9 = NEW TRADE INTERRUPTIONS

x12= TRADE VARIABILITY

x14= TRADE TYPE

x16= THE PERIODIC INFLUENCE

x17= WEEKLY WEATHER INFLUENCE

x18= THE BAD WEATHER INFLUENCE

x19= THE WORK PLACE LOCATION FACTOR

Hence, weekly productive time is advanced as a function of: task/operatives variability; management team influence; design/quality interruptions; new trade influence; trade variability; trade type; the periodic influence; weekly weather influence; the bad weather influence; the work place location factor. Only two of the ten variables are hypothesized to have a positive influence indicating the presence of many disturbances for the periodic model. The variables are transformed and retrieved in the following ways:-

i. PRODUCTIVE AND THE TOTAL NUMBER OF OBSERVATIONS

Data on productive time is obtained from the output of date vs. technique (example Appendix D.6) and the way it is retrieved has already been discussed. The study covered 82 weeks but observations were interrupted by several weeks of holiday. The interruptionss will not pose any problem since the data is not going to be analysed cumulatively. A total of 188 data points were obtained for the analysis as the data is classified according to floor level. Appendix

C.1 shows the observed productive hours (PH), the division into observed productive observations (NP) is done during the analysis. The total number of observations (NT) are transformed in the same manner from the total hours (PT).

ii. TASK/OPERATIONS VARIABILITY (x1)

Operations variability is already defined in Chapter 6. The larger the number of operations executed can indicate that more varied resources are utilized. Manpower needs to be controlled and monitored and supervision level therefore must be high. If supervision level is low and the workforce is not properly controlled, there is bound to be inefficient time utilization. Unavailability of resources on time at the work place will also cause delay and the possibility of delay would be more apparent with more operations.

FIGURE 8.2

TRANSFORMING VARIABLES X1 (MODEL A)

i. Create table for weeks and number of operations in building element classification.

ii. Refer table 12 and 13, start from stage 1 (building element) with week 1 to 82 and count and transfer to table below.

iii. Total right margin = number of operations per week = operations variabilities.

iv. Transfer total to data file in VAX for model A .

EXAMPLE OF TABLE

WEEK NO.	OPERATIONS IN BUILDING ELEMENT CLASSIFICATION											TOTAL
	1	2	3	4	5	6	7	8	9	10	 33	
1												Xa
2												Xb
3												
4												
5												
6												
|												
82												

x1a= total number of operation for week 1

x1b= total number of operation for week 2

FIGURE 8.3

TRANSFORMING VARIABLES X5 (MODEL A)

MH

i. Refer table 10 and 11, look at trade ENG and OFF and total the hours for week 1.

ii. Transfer to data file in VAX for model A.

iii. Repeat i and ii for week 2 to 82.

SL

i. Refer table 8 and 9, look at activity SU and total the hours for week 1.

ii. Transfer to data file in VAX for model A.

iii. Repeat i and ii for week 2 to 82.

The delay will also be more marked when critical operations are planned. If critical operations cannot be executed then other operations are held up. Redeployment of manpower resources to another operation will also mean that new work places need to be set up and preparation needs to be done for new operations. This does mean that with more operations, the possibility of change over from one operation to another exist. Thus a higher number of operations could result in lower productive time. With these possibilities, it were possible to hypothesize that the greater the operations variability, the less productive time will be achieved, thus the influence can be advanced as negative.

The operations variablity can be measured by counting the number of operations executed per week from the output of stage/date versus operation (example Appendix D.8) and the way it is transformed is shown in Figure 8.2 and Appendix D.8.

iii. MANAGEMENT TEAM INFLUENCE AT WORK PLACE (x5)

A more detailed and perhaps a better measure of the influence of management presence is the time expended on supervision activity only. Since their total time are expended on other activities apart from activities which is supervisory in nature, the general influence of their presence can also be measured. In theoretical model A, both the variables can be measured. For both the management hours (MH) and supersivsion hours (SL) the actual hours expended per week will be used. The extraction is directly from the table of date vs. trade (exmple ouput in Appendix D.7) for the measure of MH while for SL, table date vs. activity (example output Appendix D.6) is used. The transformation for this variable for theoretical model A is shown in Figure 8.3 and Appendices D.6 and D.7.

Both MH and SU are two measures measuring one influence. For this reason, variable MH and SL will be selected on the basis of the one which will give a better measure to the model and will be dealt with in Chapter 9.

iv. DESIGN/QUALITY INTERRUPTIONS (x7)

The influènce of the amount of repeat work on the productive time achieved weekly will also be examined. The output of date versus technique (example output in Appendix D.6) will be used to extract the data. The transformation is the same for variable x5 (SL) in Figure 8.3 except the activity of work repeat (RT) is used. Their influence will be measure by scaling the actual hours expended on RT.

v. NEW TRADE INTERRUPTIONS (x9)

The influence of the newly arrived trade to acclimatize and familiarize themselves on site should also be examined. New trade types introduced on site can be found in output date versus trade (example output in Appendix D.9). The unit of measure will be the number of new trade type introduced at a particular floor level each week. The transformation is described in Appendix D.9.

vi. TRADE VARIABILITY (x12)

The number of trade types per week will vary. This variation will be influencing productive time. The larger the number of trade types, the lower the productive time. In addition, the influence of trade mainly employed for the week can also be significant. Usually there will be more than one trade that is mainly employed. There are thus two possible measures of trade variability for the theoretical model A; the number of trades employed per week (TVA) and the number of main trades employed per week (TVB).

Output of date versus trade (example Appendix D.7) will yield the number of trades employed per week. When this is counted, the unit will be the number of trades employed per week. To determine the number of main trades employed, a base line calculation is done, which is calculated by dividing the total hours of operatives per week divided by the total number of trades. Any trades with number of hours greater than this value is considered as the main trade employed. Since there may be a high correlation between these two measures, the choice of which to use will be made in the actual analysis. If there is low correlation, indicating no relationship between the TVA and TVB, then another variable can be easiliy created and both can be used.

vii.TRADE TYPE (x14)

The influence of the trade type per week is essentially a categorical scale of measurement. This is included because variability may arise by reason of differences in trade type rather than in the other factors. However, only the influence of trade type which are mainly employed for a particular week may be examined for this model. The categorical scaling is given in Appendix C.1 data on TT (Trade Type) and consists of 31 category. This categorical scaling is very large. In GLM, each level of categorical variable will have a separate intercept and treated as if it were a variable by itself. This means that a total of 31 parameter estimates will be given. Initial regression using all the variables, revealed that the regression estimate varies with varying t-values and in essence validating the use of a separate category. The large number of parameters will mean more interaction effects will have to be examined, as well as the difficulty of forming a simpler interpretation. Thus the influence of trade type will be exmained from two types of scaling only.

For each week the trade category which has the highest number of manhours expended will be recorded and this is obtained from table date vs. trade (example output in Appendix D.7). The hypothetical model seeks to investigate the influence of trade type under the control of the main contractor. For model A, only 11 trades are mainly employed throughout the study corresponding to each week they are recorded. Scaling 1 is for trades not under the control of the main contractor and scaling 2 for trades under the control of the main contractor. Therefore, variable x14 measures the influence of the main trade type employed per week (MTTA) and is different from the measure for theoretical models B and E where the measure will be specific to the trade type concerned. This variable will be transformed during the analysis.

viii.THE PERIODICAL CLASSIFICATION(x16)

Rank scaling will be used as the unit of periodic influence. The months of the year are first grouped according to the first, second, third and fourth quarter. It is expected that the quarter which has the most influence on productive time is the first, followed by the fourth, second and the third quarter and given the scale 4, 3, 2, 1 respectively. It should be noted that the variable if it becomes significant should be interpreted as representing the period of the year and not the actual seasonal influence.

ix. WEEKLY WEATHER INFLUENCE (x17)

The daily diary sheet of the study provides a qualitative summary of weather conditions (Appendix B.1). This information could also be used to examine the influence of the weekly variation of weather which may not necessarily result in the actual loss of working hours, but which may necessitate moving to another work place and thus reduce productive time. The weather conditions for each week are tabulated, then the summary of weather conditions for each week is obtained and a nine point scale is apportioned to each week to be used for the analysis (Appendix D.10).

x. THE BAD WEATHER INFLUENCE (x18)

Its influence on productive time will be obtained from the output of date versus acticity (example output in Appendix D.6). The RO activity category is used for this purpose. This is actually not strictly an activity but a cause of not working. But because it can easily be apportioned during observation, it is sampled as an activity category. Therefore the inclusion of this variable is justified. The unit of measure used is the actual hours lost due to bad weather. The three measures of weather influence will be examined in the initial exploration of the analysis, to determine the correlations between them, and deletion will be made if necessary.

xi. THE FLOOR LEVEL FACTOR (x19)

It is hypothesized that the higher floor will have higher proportion of productive time than the ground level because of less interruptions to working. Appendix C.1 shows the data on FL to be in 3 categories. Hypothesis on this variable in Chapter 6 intends to examine the productive time in the upper level and the ground level. Thus only two levels scale will be used. This rescaling means that all floor 1 and 2 data will be grouped together under level 2 and that the productive time in upper level will be more than the lower level.

will be more than the lower level.

8.8 THEORETICAL MODEL B- TRADE PRODUCTIVE TIME

Overall trade productive time will be influenced by many variables much in the same way as theoretical model A. As such, those arguments that have been covered above will not be repeated. The model will consists of productive time data grouped into trades. The trades productive time is hypothesized to be influenced by 8 variables capable of being transformed and measured. The postulation of the relationship is in the formula:-

$$Bp = a - x1 + x15 - x14 + x13 - x7 - x8 - x18 + x19$$

where:-

x1 = TASK/OPERATIONS VARIABILITY

x15= TRADE DURATION

x13= TRADE SIGNIFICANCE

x14= TRADE TYPE

x8 = THE INTERFERENCES TO THE CONTINUITY OF TRADE EMPLOYMENT

x7 = DESIGN/QUALITY INTERRUPTIONS

x18= THE BAD WEATHER INFLUENCE

x19= THE WORK PLACE LOCATION FACTOR

Trades productive time is thus advanced as a function of: task/operatives variability; trade duration; trade significance; trade type; interference to the continuity of trade employment; design/quality interruptions; the bad influence indicating the presence of many disturbances. There are several other measures which would like to be included such as the management team influence, but cannot be included because of the database limititation. The variables are transformed and retrieved in the following ways:-

i. PRODUCTIVE AND THE TOTAL NUMBER OF OBSERVATIONS

Output tabulations trade versus technique (example Appendix D.3) yield total manhours expended for productive activities for each trade. A total of 28 different trades were employed for the duration of the study. Their lengths of employment and their significant differ. A total of 68 data units are obtained when the trades are separated into various floors. The observed productive hours and total hours for each trade are transfered to the data file in VAX (Appendix C.2) and reduced to the number of observations and total number of observations during the analysis.

ii. TASK/OPERATIONS VARIABILITIES (x1)

For each trade type information on how many operations are undertaken can also be obtained. Table stage/operation versus trade (example Appendix D.4) will yield information on the number of operation each trade type has undertaken. The operations variability per trade is defined as total number of operations coded for that particular trade. The transformation is the same as for variable x1 in model A described in figure 8.2 except that a different table is used and the heading is for each trade instead of for each described in figure 8.2 except that a different table is used and the heading is for each trade instead of for each week.

iii. TRADE SIGNIFICANCE (x13)

Trade influence on its own productive time may also be examined from their significance. Trade significance is defined as a proportion of the total time of each trade type to total time of all operatives onsite. The measure is the total manhours per trade divided by the total observed working hours of manpower for the site. Table trade versus technique (example Appendix D.3) is used to obtain the information.

iv.TRADE TYPE (x14)

Trade type influence is essentially a categorical scale measurement. The scaling is 1 for trades not under the control of main contractor and 2 for trades under the control of main contractor. The variable has been described in theoretical model A, except that the variable in theoretical model A measure the influence of main trade type while the variable x14 in this model measure the influence of each trade according to its type. Variable x13 and x14 are also essentially two different measures; x14 variable examined group influence and x13 variable examined the significance of the trade in relation to overall manhour expenditure on site. The influence of either however, will not in aggregate reflect the influence of manpower on its own productive time without taking other considerations.

v. TRADE DURATION (x15)

The length of time each trade type employed can be measured only in terms of the number of weeks they were employed. Variable x13 measure their significance in relation to overall manhour expenditure. Variable x15 will measure the length of their employment in a broader unit because it will not take into account of short breaks in employment. Table date versus trade (example Appendix D.7) are used to transformed this variable. The way it is done is described in Appendix D.7 and figure 8.4.

vi.INTERFERENCES TO THE CONTINUITY OF TRADE EMPLOYMENT (x8)

Continuity of employment for each trade type can be measured from the number of times work ceased to continue for the trade concern. The same table as variable x15 is used and the same step applies except the number of times the trades are not observed on site will be counted. The unit is thus the number of times instead of the number of weeks. This measure should enable an examination of the effect of the number of visit/break on productive time to be made. See Appendix D.7 for example of the transformation.

FIGURE 8.4

TRANSFORMATION OF VARIABLE X15 (TMB)

i. Look for each trade type and count the number of weeks in which they are observed in table t10 and t11.

ii. Total and transfer to data file in VAX.

iii. Repeat i and ii for all trades.

vii. DESIGN/QUALITY INTERRUPTIONS (x7)

For theoretical model B, the activity RT will also be used but from the table trade versus technique (example Appendix D.3) measured in actual manhours expended by each trade for the activity.

viii. BAD WEATHER INFLUENCE (x18)

The same type of measurement as done with theoretical model A but the transformation is from the table trade versus technique (example Appendix D.3).

ix. FLOOR LEVEL FACTOR (x19)

Same as for theoretical model A.

8.9 THEORETICAL MODEL C - ELEMENT PRODUCTIVE TIME

Overall building element productive time will be influenced by many variables but essentially having different combination of variables than theoretical model A and B. The model will consists of productive time data grouped into various buiding element clasifications. The building element productive time is hypothesized to be influenced by 11 variables capable of being transformed and measured. The postulation of the relationship is in the formula:-

$$C = a - x1 + x3 + x2 - x4 - x12 - x14 - x7 - x6 + x10 + x19 + x5$$

where:-

x1 = TASK/OPERATIONS VARIABILITY

x2 = TASK/OPERATIONS SIGNIFICANCE

x3 = TASK/OPERATIONS CONTINUITY

x4 = TASK/OPERATIONS TYPE

x5 = MANAGEMENT TEAM INFLUENCE AT THE WORK PLACE

x6 = THE INTERFERENCE TO THE CONTINUITY OF TASK/OPERATIONS

x7 = DESIGN/QUALITY INTERRUPTIONS

x10= RATIONALIZED DESIGN TYPE

x12= TRADE VARIABILITY

x14= TRADE TYPE

x19= THE WORK PLACE LOCATION FACTOR

Thus building element productive time is advanced as a function of: task/operations variability; task/operations significance; task/operations continuity; task/operations type; management team influence at the work place; the interference to the continuity of task/operations; design/quality interruptions; rationalized design type; trade variability; trade type; the work place location factor. Six of the eleven variables are hyptohesized to have a negative influence indicating that buidling element productive time is influenced as much by the disturbance and the positive variables. This is because observed productive time for this model has been increased due to the data collection and processing methods which do not take into account presence disturbances such as the bad weather influence. The variables are transformed and retrieved in the following ways:-

i. PRODUCTIVE AND THE TOTAL NUMBER OF OBSERVATIONS

Element productive time model contains a total of 79 units which consists of 33 building elements classifications from three floors. Output tabulations stage versus technique (example Appendix D.1) yield total manhours for productive activities for each building element. The observed productive hours and total hours for each building element are transfered to the data file in VAX (Appendix C.3). Since the total hours include the management hours this is then deducted during the analysis to give the total actual observed working hours and reduced to the number of observations and total number of observations during the analysis.

ii. TASK/OPERATIONS VARIABILITIES (x1)

For theoretical model C, the operations variability for each element will be the number of operations carried out for the element. Table stage/operations versus trade (example Appendix D.4) is used. The transformation is as described in Figure 8.5.

FIGURE 8.5

TRANSFORMATION OF VARIABLE X1 FOR MODEL C

i. Examined table t4 and count the number of operations executed for a building element from the right hand side margin.

ii. Transfer total to VAX

iii. Repeat i and ii for each building element.

iii. TASK/OPERATIONS SIGNIFICANCE (x2)

Building element significance is the significance of building element relative to other building element in the model. Table element versus technique (example Appendix D.1) is used and the step is much the same way as variable x13 (trade significance).

iv. TASK/OPERATIONS CONTINUITY (x3)

Building element continuity will influence the productive time because a longer planned element would mean more visits is necessary. Table stage/date versus operation (example Appendix D.8) are used. The transformation is done by counting the number of weeks for each building element using the table but only using the total at the right hand side margin. Appendix D.8 gives an example. The data is then transferred to the appropriate data file in VAX.

v. TASK/OPERATIONS TYPE (x4)

Elemental classification is included to make sure that the variation does not account from the variation in elemental classification only. The original scaling is 33 categorical level corresponding to 33 elemental classifications (Appendix C.3). Again the same treatment as with trade types (x14) are made. The hypothesis in Chapter 6 for this variable is that the influence of services and superstructure elements will be negative to the productive time achievement. The scaling is thus to 1 for other classification of building element and 2 for the superstructure and services. The practical issues in both of these cases justify the broader level of examination. Future work should consider some of rank or ordinal scaling for both of these variables.

vi. MANAGEMENT TEAM INFLUENCE AT WORK PLACE (x5)

There are two measures of management presence which are possible for this model. The first can be obtained for supervision level form table element versus technique (example Appendix D.1) which used the activity SU from the table. The second is the actual management presence (MH) form table stage/operation verus trade (example Appendix D.4) where the total hours of trade ENG and OFF for the element is taken and transferred. Since both measures will involve the same problem as variable x5 in model A, the treatment and choice of the variable will be made in Chapter 9. Both the MH and SL data are transferred to the appropriate data file in the VAX.

vii. INTERFERENCE TO THE CONTINUITY OF TASK (x6)

This variable is derived much in the same way the variable x8 (the interference to the continuity of trade employment). Tables T12 and T13 (example Appendix D.8) which are used for the variable x3 (task/operations continuity) are used again. The unit is the number of times there is a break in employment for building element classification. Appendix D.8 shows the example of a data unit is transformed for this variable which are then transferred to the VAX.

viii.DESIGN/QUALITY INTERRUPTIONS (x7)

Table T1 (Appendix D.1) is again used and the activity RT is extracted and transferred to VAX.

ix. RATIONALIZED DESIGN TYPE (x8)

The type of design is decided by the criteria set out in Chapter 6. The scaling is 0 for building element with no apparent design rationalization criteria included in the design and 1 for the element with design rationalization. Appendix C.3 (DT) shows the original five levels scaling for design rationalization. The original scaling fed into the VAX is a five point scaling which is reduce during analysis for practical reasons. It should be noted that this a very subjective measure of the influence of design rationalization and more comprehensive measure cannot be accommodated for this research.

x. TRADE VARIABILITY (x12)

The different trades executing each building element can be examined from table stage/operation versus trade (example Appendix D.4). Appendix D.4 shows the example of how this variable is transformed. Two type of measures which are used (TVA and TVB) have been described in theoretical model A.

xi) TRADE TYPE (x14)

For each element, trades variabilities (x12) influence can be examined. Not all the trades are however, mainly utilized for a particular element. With the hypothesis that the trades for the main contractor influence the productive time negatively, the influence of the main trade type can also be examined in this way. This is done by examining Table T4 again. The actual manhours expended by each trade type can be examined at the right hand total as in Appendix D.4. The trade with the most manhour expenditure for the element are noted and are then classified according to the classification for this variable in model A. Appendix D.4 shows an example of transformation.

xii. FLOOR LEVEL FACTOR (x19)

The scaling is the same as in model A and B.

8.10 THEORETICAL MODEL D- OPERATIONS PRODUCTIVE TIME

Operations productive time will be influenced basically by the same variables as in theoretical model C because both are concerned with task execution. The model will consists of productive time data grouped into various operations which is related to a particular buiding element clasification. The operations productive time is hypothesized to be influenced by 10 variables capable of being transformed and measured. The postulation of the relationship is in the formula:-

$$Dp = a + x5 + x3 - x4 + x2 - x12 - x14 - x7 - x6 + x10 + x19$$

where

x2 = TASK/OPERATIONS SIGNIFICANCE

x3 = TASK/OPERATIONS CONTINUITY

x4 = TASK/OPERATIONS TYPE

x5 = MANAGEMENT TEAM INFLUENCE AT WORK PLACE

x6 = THE INTERFERENCE TO THE CONTINUITY OF TASK/OPERATIONS

x7 = DESIGN/QUALITY INTERRUPTIONS

x10= RATIONALIZED DESIGN TYPE

x12= TRADE VARIABILITY

x14= TRADE TYPE

x19= THE WORK PLACE LOCATION FACTOR

Thus operations productive time is advanced as a function of: task/operations significance; task/operations continuity; task/operations type; management team influence at the work place; the interference to the continuity of task/operations; design/quality interruptions; rationalized design type; trade variability; trade type; the work place location factor. Five of the ten variables are hypothesized to have a positive influence indicating that operations productive time is influenced equally by the positive and negative disturbances and is much the same as the theoretical model C. Only the varaible x1, which is concerned with task variablity is not in this model because logically this variable cannot be measured for this model.

i. PRODUCTIVE AND THE TOTAL NUMBER OF OBSERVATIONS

Operations productive time theoretical model contains a total of 348 data units broken down from the building elements classifications from three floors. Output tabulations stage/date versus technique (example Appendix D.2) yield total manhours expended for productive activities for each operation. The observed productive hours and total hours for each building element are transferred to the data file in VAX (Appendix C.4). Since the total hours include the supervision hours this is then deducted during the analysis to give the total observed working hours and reduced to the number of observations and total number of observations during the analysis.

ii. TASK/OPERATIONS SIGNIFICANCE (x2)

Task significance is the significance of task relative to other tasks in the model. The measure is obtained as model C except that Table T1 (Appendix D.1) are used and the unit is in percentage.

iii.TASK/OPERATIONS CONTINUITY (x3)

Task/operations continuity will influence the productive time because a longer planned operation would mean more visits are necessary. Tables T12 and T13 (Appendix D.8), date versus operations are used. In model C the right hand margin is used. For this model, the number of weeks for each particular operation are counted as shown in Appendix D.8.

iv. TASK/OPERATIONS TYPE (x4)

This variable is derived in the same way as for model C. Essentially this means that each operation either belongs to the superstructure and services or the other elements.

v. MANAGEMENT TEAM INFLUENCE AT WORK PLACE (x5)

Only one measure is possible for this model; the supervision level (SL). The data is obtained from table stage/date versus technique (Appendix D.2) with specific reference for activity SU. As such no problem as to which measure to be used for this variable will be encountered.

vi. THE INTERFERENCE TO THE CONTINUITY OF TASK/OPERATIONS (x6)

This variable is derived much in the same way the variable x8 (the interference to the continuity of trade employment). Tables T12 and T13 (Appendix D.8) which is used for the variable x3 (task/operations continuity) for model C and this model is again used. The unit is the number of times there is a break in employment for building element classification. However instead of using the figure in the right hand total the break for each operation is counted. Appendix D.8 shows the example of a data unit transformed for this variable which are then transferred to the VAX.

vii.DESIGN/QUALITY INTERRUPTIONS (x7)

As already discussed in factor model A, but specific to each operation and Table T2 (Appendix D.2) is used with the data in activity RT transferred to VAX.

viii.RATIONALIZED DESIGN TYPE (x10)

Same as in theoretical model C.

ix. TRADE VARIABILITY (x12)

This variable will be examined from table T4 (Appendix D.4) which is used for the model C. The data used will be specific to each operation as shown in Appendix D.4.

x. TRADE TYPE (X14)

The same table as in x12 is used for this variable and the same rule which is used to transform x14 in model C is used.

x. WORK PLACE LOCATION FACTOR (x19)

The variable has the same scaling as in other models.

8.11 THEORETICAL MODEL E - GANGS PRODUCTIVE TIME

Gangs productive time will be influenced by many variables much in the same way as the theoretical model B. Gang is defined as the trade observed executing operations for a particular building element. This definition is used only for this research due to the ouput restrictions of BRESAAP. The conventional definition of gang does not apply to this research. The findings will thus have to be read in conjunction with the definition used and may have to be separated from the more conventional definition of gang. The definition of gang within this study was used consistently and the consistency was maintained thoroughout the study. Although this model should be more closely related to model B than with model C, the constraints imposed by the algorithm in BRESAAP mean that for gangs productive time the influence of external factors cannot be examined. The model will consists of productive time data grouped into trades in particular building element. The gang productive time is hypothesized to be influenced by 10 variables capable of being transformed and measured. The postulation of the relationship is in the formula:-

$$Ep = a + x1 + x5 - x4 - x14 + x15 + x13 - x7 - x8 - x11 + x19$$

Where:

x1 = TASK/OPERATIONS VARIABILITY

x4 = TASK/OPERATIONS TYPE

x5 = MANAGEMENT TEAM INFLUENCE AT WORK PLACE

x7 = DESIGN/QUALITY INTERRUPTIONS

X8 = THE INTERFERENCE TO THE CONTINUITY OF TRADE EMPLOYMENT

x11= TASK INTERDEPENDENCE OF TRADE

x13= TRADE SIGNIFICANCE

x14= TRADE TYPE

x19= THE WORK PLACE LOCATION FACTOR

x15= TRADE DURATION

Thus trades productive time is as a function of: task/operations variability; task/operations type; the management team influence at the work place; design/quality interruptions; the interference to the continuity of trade employment; task interdependence of trade; trade significance; trade type; the work place location factor; trade duration. Five of the ten variables are hypothesized to have a negative influence indicating an equal balance of positive and negative disturbances. There are several other measures which would like to be included such as the the task variabilitites, but cannot be included because of the database limitation. The variables are transformed and retrieved in the following ways:-

i. NUMBER OF PRODUCTIVE OBSERVATIONS AND TOTAL OBSERVATIONS

Output tabulations stage/trade versus technique (example Appendix D.5) yield total manhours expanded for productive activities for each gangs. A total of 325 different gangs were formed and disbanded during the duration of the study. The data on the observed productive hours and total hours were reduced and rounded before transfering to the VAX because of the problem in doing a generalized calculation for all data of NT and NP during the analysis. Appendix C.5 show the data file for this model.

ii. TASK/OPERATIONS VARIABILITY (X1)

Table stage/date versus trade (Appendix D.4) yield information on the number of operations each gang undertook. The number of operation gang have undertaken for the element is counted and transferred to the data file as shown in Appendix D.4.

iii.TASK/OPERATIONS TYPE (x4)

This variable used the same scaling as in model B. This means that each gang will be coded according to the type of element they are working in.

iv. MANAGEMENT TEAM INFLUENCE AT WORK PLACE (x5)

Management team influence on each gang productive time working on various elements cannot be transformed directly form the output tabulations. The database will not yield exactly the level of management presence for particular gang per element. This is again because of the way the data can be extracted. Ill conditioned data (317) may be prominent for this variable and thus if the variable is not significant the interpretation of the consequence of this problem has to be taken into account. The next best source is the information associated with the element the trade were working. Three measures can be obtained pertaining to management team influence and all are related to the element the trade were working in. They are; the total time management spent at various element (ME); the total time expanded in operations in which gang were coded (MH);

the time when management and gang were coded each week for a particular element (MW).

Clearly from the foregoing, three problems arise:-

a. Which one of the above measure to use?
b. If all are used will the three influence have a much greater influence than other variables in other categories.
b. If all are used, the three variables could be highly correlated.

The three variables will only be an approximate measure of the influence of management team, the exact influence of management team on the gang productive time on each element cannot be known. Due to this generality, it is decided that the measures will be correlated using their sums of squares of products. If there is a high degree of correlation, then only one will be used in order of MW because of more specific measurement determined a priori. If no siginifcant correlation exist MW will be used. If MW is not significant it will be replaced by MH. If MH is also eliminated, then ME will be used. It is considered ME is the most general measurment among the three variables.

The transformation are done as follows:-

a. For ME, the output of table stage/operation versus trade (Appendix D.4) is used. The manhours of OFF and ENG are totalled and transferred to all relevant gangs in the element.

b. For MH, the same table is used, but only the total time of OFF and ENG in operations in which gangs were coded are totalled and transferred to relevant gangs. Thus MH will have a different measure from ME.

c. For MW, the output of table stage/date versus trade (Appendix D.9) is used. Following the same procedure for MH, MW is calculated by totalling the OFF and ENG hours in weeks for the element in which both the gang and management were coded. This are then totalled for each gang and transferred to the data file.

v. DESIGN/QUALITY INTERRUPTIONS (x7)

As already discussed in factor model A, but specific to each gang and Table T7 (Appendix D.5) is used with activity RT used to obtain data on the variable.

vii.TASK INTERDEPENDENCE OF TRADE (x11)

For this measure table stage/operation versus trade was used (Appendix D.4). The interdependence of trade for each gang is measured by counting the number of other trades working in an operation trade worked. If a gang worked for one operation and there were seven other trades which has executed the operation, the variable unit for the gang is seven. However since the productive time data measure productive time for gangs in a particular element the total number of other trades in all the operations trades executed were counted and totalled.

vii.TRADE SIGNIFICANCE (x13)

Trade influence of its own productive time may also be examined from their significance in the element. The measure is the total manhours expanded in each element divided by the working hours of gang in the element. Table T7 (Appendix D.5) was used to calculate the significance and the unit is in percentage.

ix. TRADE TYPE (x14)

Trade type influence is a categorical scale of measurement and has been described in theoretical model B. For each gang, the scale which has been given were allocated during the analysis.

x. TRADE DURATION (x15)

The total time expanded by each trade can also be known but rather than taking the total time, the other measure is the number of weeks in which trade were coded working in that element. The output of stage/date versus trade (Appendix D.9) was used. The calculation is the same as in theoretical model B for the relevant variable.

xi. THE INTERFERENCE TO THE CONTINUITY OF TRADE EMPLOYMENT (x8)

Discontinuity of employment for each gang can be measured from the number of times gangs were not observed on site and the same output as in x15 above was used, while the transformation is the same as in theoretical model B for this variable.

xii) THE FLOOR LEVEL INFLUENCE (x19)

The same as in other models.

8.12 DATABASE RETRIEVAL

The process of retrieval of all variables transformed in the last few sections have been described. All the variables were transferred into the VAX system via its editor by creating five separate data files each corresponds to the theoretical models. Appendices C.1-C.5 lists all the variables in the five data files. Each file is a theoretical model of productive time specific to the attributes concerned. Table 8.3 summarizes all the variables used in the model with the direction of hypothesized influence indicated. Table 8.4 summarized the unit of measure for all the variables.

8.13 SUMMARY

For each of the model a further two objectives can be set.

i. To test the validity of the specific theoretical models in relation to the postulated influence of the variables.
ii. To test the direction of influence of each variable based on hypothesized relationships.

TABLE 8.3 SUMMARY OF VARIABLES IN MODELS

	A	B	C	D	E	TOT
x1	-	-	-		-	4
x2			+	+		2
x3			+	+		2
x4			-	-	-	3
x5	+		+	+	+	4
x6			-	-		2
x7	-	-	-	-	-	5
x8		-			-	2
x9	-					1
x10			+	+		2
x11					-	1
x12	-		-	-		3
x13		+			+	2
x14	-	-	-	-	-	5
x15		+			+	2
x16	-					1
x17	-					1
x18	-	-				2
x19	+	+	+	+	+	5
TOT/-VE	8	5	6	5	5	
TOT/+VE	2	3	5	5	5	
TOTAL	10	8	11	10	10	

TABLE 8.4 UNIT OF MEASURE FOR VARIABLES

	A	B	C	D	E	TOT
x1	N	N	N		N	4
x2			%	%		2
x3			W	W		2
x4			C	C	C	3
x5	H			H	H	3
x6			N	N		2
x7	H	H	H	H	H	5
x8		N			N	2
x9	N					1
x10			C	C		2
x11					N	1
x12	N		N	N		3
x13		%			%	2
x14	C	C	C	C	C	5
x15		W			W	2
x16	R					1
x17	R					1
x18	H	H				2
x19	C	C	C	C	C	5

Note:
N = Number ; H = Hours ; C = Category ;
% = Percentage ; R = Rank; W = Week

CHAPTER NINE

CHAPTER NINE

9 GENERALIZED LINEAR MODELLING

9.1 MODELLING OF THEORETICAL MODELS

Modelling of transformed data of all productive time theoretical models utilize the Generalized Linear Modelling (GLM) technique briefly described in Chapter 5. The statistical package use is the GENSTAT5 (318) which is one of the two packages that accommodate GLM and is available to model the data.

GLM is a general form of classical linear regression thus most of the use and procedures associated with regression methodology also apply to the technique. As a tool for statistical data analysis regression methodology can be used to select the best subset of variables which can describe the pattern of variation in the data from the list of variables specified in the theoretical model. In statistical terms, a subset of variables is also termed as a model. The aim is therefore to the fit the data to the specified variables and choose the best subset of variables. The process of model fitting in this research will be undertaken in four steps:-

i. Exploratory Data Analysis

ii. Model Specification (319)

iii.Model Checking

iv. Model Selection and parameter estimation(320).

In model specification, Gunst and Mason (319) emphasized that the relevant variables must be in the database and the prediction equation is defined with a correct functional form for all the predictor variables. Parameter estimation is more difficult to perform because it demands correct model specification, accurate prediction and good estimation from the database. Both model specification and parameter estimation thus depend on the data, the limitation of the database and other regression assumptions which must be satisfied. Model checking on the other hand is undertaken to weed out problems associated with regression modelling and satisfying regression conditions before multiple regression modelling could be applied to the data.

9.2 EXPLORATORY DATA ANALYSIS

Error checking during transformation of data from BRESAAP output to the data files in VAX has been carried out during the process of transformation. Errors can arise from digit transposition, incorrect value/s for a variate/s, incorrect value/s for an observation/s. GENSTAST can also checked that the errors of transferred data are reduced to a minimum with the READ directive activated. The directive undertook this process automatically in two ways:-

i. It reported on errors in the data while reading from data file. The directive makes a distinction between serious and minor errors. Minor errors are concerned with the individual element of the data. Serious errors fall into 2 categories. Firstly, errors that inhibit any attempt to execute the read statement. Secondly, errors that cast doubt on validity of the data after they have been read. The program automatically be aborted when the first serious errors occurs. The minor errors and errors associated with the second serious errors if present in large scale will also cause the program to be aborted, otherwise it will continue with just the warning message printed. In all cases data were re-checked to correct the errors.

ii. The directive also prints automatically a summary of the quantitative variable statistics, the minimum value, maximum and mean and the number of units missing. This also facilitates the checking of errors. Appendices E.1-E.5, shows the relevant statistics.

There is no apparent error left from all the data files of the five models after the above process were executed but there is no infallible way of finding all errors in the data sets. Further checking of data will be done in Stage 3 with respect to outliers and influential observation. Other checks such as proposed by Wetherill (321) were not carried out except that, the summary statistics of each variables are examined in Appendices E.1-E.5 for the purpose of casually looking at the characteristics of the data. Most of these data are skewed to one side reflecting some non-normality in their distribution.

9.3 MODEL SPECIFICATION

GLM specifies the components of its model in a different way from the classical linear model to take into account the wide range of data distribution it is intented to accommodate. It is necessary to describe in simple term the theory of GLM, as it differs widely from classical linear regression techniques. The specification of the systematic parts of the model are described in McCullagh and Nelder (322) and Baker and Nelder 1986 (323). The specification consists of three main components:-

i. The random response variables which are assumed to share the same distribution from the exponential family and in this research, the binomial distribution. The GLM model will thus consist of the response measure i.e. the productive time observations (NP) and the binomial denominator i.e. the total number of observations for a particular case (NT).

ii. A set of parameters Betha and explanatory or independent variables

iii. A link function which relates the linear predictor to the expected value of means. The link function applicable to binomial distribution is the logit or the identity link function.

The similarity with the classical models are in (i) and (ii) above but assuming normal distribution thus without the binomial denominator. In classical regression model, the link function is absent and the more common method of computing the relationship is with Least Square (LS) method. With GLM, Maximum Likelihood Estimate (MLE) method is used, together with the link function applicable to the exponential family of distribution. As in the classical model many assumptions have to be made on the model which will be discussed in model checking. However, with the used of GLM, some of the assumptions may not have to be satisfied.

In sampling productive time, there are two possible values. Where Y=1 is productive and Y=0 is unproductive. Intermediate values of indirectly productive activities may also be observed and recorded. These are not considered as response variables. In construction work the probability that any observation Yi=1 is p and (1-p) for unproductive observation. Each unit of Yi is associated with a vector of explanatory variables or covariates (xi,...xk). The vector of covariates would consists of measured variables thought likely to influence the probability of a productive response. The principle objective is to investigate the relationship between the response probability p and the covariates xi,...,xk. A subset of xs is of primary importance but due allowance must be made for the effect of the remaining covariates.

Binary data can also be grouped or ungrouped. McCullagh and Nelder (324) described the distinction between both. The grouped data is relevant for the data to be analysed in this research. The distinction is made because of the method of statistical analysis which may not be applicable to ungrouped data and the approximations which can be made on both types of data. Grouped data are more easily analysed because the method of analysis and approximations can be easily made as compared to ungrouped data.

Model specification for each of the theoretical models is specified in terms of the 'binomial model' and are thus as follows :-

i. The reponse variable is NP (productive observation)

ii. The binomial denominator is NT (total observation)

iii.The link function is Logit

iv. The TERMS for each theoretical model.

The first three specifications have been described. The TERMS for all thoeretical models will consist of the variables specified in the models inlcuding any factorial expansion that is needed. If there are 11 variables there will be 2048 possible terms in the model. This essentially will be an impossible analysis to undertake. and it will be difficult to interpret the results. For this reason, model selection will be in two stages. For the purpose of model checking only the main effects will be used which means that only the variables themselves will be used as the terms. This will be carried over to the first stage of model selection. Factorial expansion of 2 i.e. first order interaction (325) will then be used to examine the significance of interaction between two selected variables only in the second part of model selection.

9.4 MODEL CHECKING PROCEDURES ADOPTED

Model checking in this research is aimed to reduce the magnitude of problems associated with data which may invalidate the regression assumptions. Some of the checks are only relevant to classical regression while McCullagh and Nelder (326) proposed a few more steps for model checking specific to GLM. The following are checks or tests which may need to be carried out:-

i. Data must be fitted to a suitable model which must be relevant to type of data and from a particular class of model.

ii. Assumptions of distribution family of data

iii. Choice of scale and unit of measurement

iv. Error structure

v. Additivity of systematic effects (interaction)

vi. Linearity of relationships

vii. Multicollinearity

viii. Homodescacity and heteroscedasticity (variance function)

ix. Model specification error

x. Outliers

xi. Satisfactory link function

Tests (iii), (vi), (viii), (x) and (xi) will be carried as part of the model checking procedures for all models. Test (v) will be part of the second stage of model selection. The reasons for not undertaking other tests will be explained later. There are two ways to conduct these tests; by graphical means and statistical tests.

Graphical checks will be carried out first and will be followed by statistical tests when it is considered necessary.

9.4.1 CHOICE OF VARIABLES MEASURES -

Data transformed in Chapter 8 for some theoretical models contain two or three measures for a particular variable. The first step in model checking is to decide which measure for a particular variable is to be used. Clearly the decision on which measure to be used will have to rely first on the extent of linearity in the relationship. Once there is an indication of the close relationship then a decision on which of the measure to be used will have to be made. For the purpose of this research, a two step check will be made to eliminate one measure. Firstly, a correlation coefficient between the quantitative variable will be determined. A correlation coefficient measures the degree of linear relationship between two measures or variables by yielding an index of 0.0 to 1.0. The higher the indext the closer is the linear relationship. The problem lies in determining the cut-off point. When the correlation coefficient is used to determine the significant relationship between two variables, a significance test can be used to rigorously indentify the statistical significance of such relationship. Since the main aim of this research is to determine those significant independent variables in the context of their influence on the response variable and not relationship between those independent variables, the test if not carried out. A cut-off point of 0.8 will be used as has been suggested for the purpose of eliminating a variable in regression (327). Since this is only an prelimnary step the significance of 0.8 is not over-emphasized. Secondly, the choice of which measure to be removed will be made by using the Principal Component Analysis (PCA) which can also identify multicollinearity variables (328). However only the variables which are highly correlated will be examined and the one which has a higher latent vector loading will be removed from the model and the effect of removing the measure will be examined.

TABLE 9.1(a)
CORRELATION MATRIX OF QUANTITATIVE VARIABLES
THEORETICAL MODEL A

X18	1.000							
X5A	0.213	1.000						
X16	0.160	-0.131	1.000					
X12A	0.048	0.035	-0.171	1.000				
X12B	0.103	0.154	-0.091	0.831	1.000			
X5B	0.154	0.931	-0.227	0.062	0.189	1.000		
X1	0.201	0.247	-0.024	0.825	0.746	0.231	1.000	
X17	0.405	0.006	0.493	-0.386	-0.258	-0.066	-0.225	1.000
X7	0.265	0.161	0.079	0.210	0.230	0.128	0.383	0.054
	X18	X5A	X16	X12A	X12B	X5B	X1	X17

TABLE 9.1(b)
CORRELATION MATRIX OF QUANTITATIVE VARIABLES
THEORETICAL MODEL B

X13	1.000					
X18	0.632	1.000				
X7	0.707	0.605	1.000			
X15	0.794	0.410	0.649	1.000		
X8	0.274	0.153	0.391	0.646	1.000	
X1	0.783	0.299	0.642	0.888	0.411	1.000
	X13	X18	X7	X15	X8	X1

TABLE 9.1(c)
CORRELATION MATRIX OF QUANTITATIVE VARIABLES
THEORETICAL MODEL C

X5B	1.000							
X12A	0.305	1.000						
X3	0.278	0.673	1.000					
X5A	0.998	0.323	0.307	1.000				
X7	0.406	0.417	0.565	0.424	1.000			
X1	0.505	0.684	0.611	0.524	0.464	1.000		
X6	0.095	0.534	0.687	0.111	0.380	0.536	1.000	
X2	0.687	0.448	0.679	0.702	0.685	0.491	0.254	1.000
X12B	0.315	0.584	0.304	0.313	0.077	0.511	0.383	0.160
	X5B	X12A	X3	X5A	X7	X1	X6	X2

TABLE 9.1(d)
CORRELATION MATRIX OF QUANTITATIVE VARIABLES
THEORETICAL MODEL D

X12A	1.000						
X12B	0.391	1.000					
X3	0.600	0.025	1.000				
X2	0.157	-0.073	0.397	1.000			
X6	0.497	0.097	0.743	0.201	1.000		
X5	0.417	0.098	0.417	0.102	0.133	1.000	
X7	0.409	-0.007	0.583	0.199	0.355	0.424	1.000
	X12A	X12B	X3	X2	X6	X5	X7

TABLE 9.1(e)
CORRELATION MATRIX OF QUANTITATIVE VARIABLES
THEORETICAL MODEL E

X13	1.000							
X7	0.423	1.000						
X1	0.334	0.423	1.000					
X15	0.500	0.542	0.732	1.000				
X8	0.379	0.434	0.645	0.770	1.000			
X11	-0.140	0.107	0.704	0.507	0.475	1.000		
X5A	-0.122	0.024	0.387	0.246	0.084	0.447	1.000	
X5B	-0.047	0.062	0.513	0.343	0.158	0.539	0.901	1.000
X5C	-0.008	0.073	0.465	0.328	0.120	0.452	0.884	0.954
	X13	X7	X1	X15	X8	X11	X5A	X5B

TABLE 9.2(a)
THEORETICAL MODEL A
PRINCIPAL COMPONENT ANALYSIS

*** Latent Roots ***

1	2	3	4	5	6	7	8	9
3.086	1.944	1.706	0.791	0.708	0.374	0.231	0.100	0.060

*** Percentage variation ***

1	2	3	4	5	6	7	8	9
34.29	21.60	18.95	8.79	7.87	4.15	2.57	1.11	0.67

*** Trace ***

9.000

*** Latent Vectors (Loadings) ***

	1	2	3	4	5	6	7	8	9
X18	-0.11	0.42	0.34	0.12	0.70	0.42	-0.11	0.01	0.02
X5A	-0.26	0.51	-0.36	-0.14	-0.15	0.05	0.05	0.06	-0.70
X12A	-0.48	-0.27	0.17	-0.15	0.09	-0.07	0.14	0.78	-0.02
X12B	-0.48	-0.15	0.17	-0.25	0.03	-0.26	-0.69	-0.33	-0.07
X5B	-0.28	0.46	-0.42	-0.12	-0.12	-0.02	-0.08	0.10	0.70
X1	-0.50	-0.05	0.22	-0.09	-0.06	0.05	0.65	-0.50	0.08
X17	0.22	0.43	0.38	-0.19	0.10	-0.74	0.16	0.06	0.01
X7	-0.23	0.19	0.28	0.81	-0.38	-0.09	-0.12	0.08	0.00
X16	0.15	0.19	0.51	-0.41	-0.55	0.44	-0.12	0.09	0.06

TABLE 9.2(b)
THEORETICAL MODEL B
PRINCIPAL COMPONENT ANALYSIS

*** Latent Roots ***

1	2	3	4	5	6
3.860	1.014	0.637	0.321	0.118	0.050

*** Percentage variation ***

1	2	3	4	5	6
64.33	16.90	10.62	5.36	1.97	0.83

*** Trace ***

6.000

*** Latent Vectors (Loadings) ***

	1	2	3	4	5	6
X18	-0.32	0.62	0.49	-0.36	0.37	-0.08
X7	-0.42	0.20	0.17	0.85	-0.06	0.12
X15	-0.47	-0.27	-0.13	-0.25	0.15	0.78
X8	-0.29	-0.64	0.62	-0.09	-0.15	-0.29
X1	-0.44	-0.18	-0.51	0.03	0.51	-0.50
X13	-0.46	0.24	-0.27	-0.26	-0.75	-0.18

TABLE 9.2(c)
THEORETICAL MODEL C
PRINCIPAL COMPONENT ANALYSIS

*** Latent Roots ***

1	2	3	4	5	6	7	8	9
4.72	1.68	1.12	0.45	0.38	0.35	0.22	0.08	0.001

*** Percentage variation ***

1	2	3	4	5	6	7	8	9
52.41	18.63	12.49	5.01	4.22	3.90	2.41	0.92	0.02

*** Trace ***

9.000

*** Latent Vectors (Loadings) ***

	1	2	3	4	5	6	7	8	9
X5A	-0.34	0.48	0.19	0.21	-0.04	0.01	-0.19	-0.18	0.71
X5B	-0.33	0.49	0.21	0.22	-0.03	-0.02	-0.20	-0.14	-0.70
X12A	-0.35	-0.31	0.15	-0.52	-0.08	0.24	-0.65	0.09	-0.00
X3	-0.37	-0.27	-0.31	0.00	-0.50	0.03	0.24	-0.62	-0.02
X7	-0.32	0.06	-0.50	-0.22	0.68	-0.33	-0.03	-0.17	-0.00
X1	-0.38	-0.13	0.17	0.10	0.37	0.68	0.44	0.11	-0.01
X6	-0.27	-0.47	-0.11	0.71	0.03	-0.22	-0.26	0.28	0.01
X2	-0.37	0.26	-0.30	-0.21	-0.37	-0.13	0.27	0.66	0.01
X12B	-0.24	-0.23	0.65	-0.19	0.06	-0.56	0.33	-0.02	0.01

TABLE 9.2(d)
THEORETICAL MODEL D
PRINCIPAL COMPONENT ANALYSIS

***** Principal components analysis *****

*** Latent Roots ***

1	2	3	4	5	6	7
3.025	1.223	0.951	0.793	0.508	0.346	0.154

*** Percentage variation ***

1	2	3	4	5	6	7
43.21	17.47	13.59	11.32	7.26	4.95	2.20

*** Trace ***

7.000

*** Latent Vectors (Loadings) ***

	1	2	3	4	5	6	7
X12A	-0.45	0.35	0.07	0.03	0.14	0.78	-0.12
X12B	-0.12	0.77	0.25	0.33	-0.26	-0.38	0.09
X3	-0.52	-0.18	0.12	-0.13	0.12	-0.12	0.79
X2	-0.23	-0.46	0.29	0.79	-0.04	-0.00	-0.17
X6	-0.42	-0.07	0.46	-0.43	0.19	-0.35	-0.51
X5	-0.33	0.12	-0.69	0.21	0.48	-0.29	-0.18
X7	-0.41	-0.15	-0.37	-0.14	-0.79	-0.02	-0.15

TABLE 9.2(e)
THEORETICAL MODEL E
PRINCIPAL COMPONENT ANALYSIS

***** Principal components analysis *****

*** Latent Roots ***

1	2	3	4	5	6	7	8	9
4.252	2.368	0.984	0.570	0.343	0.185	0.144	0.114	0.039

*** Percentage variation ***

1	2	3	4	5	6	7	8	9
47.25	26.31	10.94	6.34	3.81	2.06	1.60	1.27	0.43

*** Trace ***

9.000

*** Latent Vectors (Loadings) ***

	1	2	3	4	5	6	7	8	9
X13	-0.13	0.43	-0.55	0.51	0.29	-0.01	0.39	-0.01	0.00
X7	-0.21	0.37	-0.84	0.07	-0.04	0.15	-0.06	0.08	
X1	-0.42	0.15	0.17	0.07	0.51	-0.44	-0.52	0.21	-0.03
X15	-0.38	0.32	0.03	0.09	-0.23	0.73	-0.37	0.15	0.04
X8	-0.31	0.37	0.28	0.15	-0.65	-0.45	0.16	-0.14	-0.01
X11	-0.36	-0.08	0.59	-0.03	0.36	0.25	0.56	-0.10	-0.08
X5A	-0.34	-0.39	-0.22	-0.05	-0.21	-0.07	0.25	0.75	-0.09
X5B	-0.38	-0.36	-0.18	0.03	-0.02	-0.04	-0.02	-0.320	0.76
X5C	-0.37	-0.35	-0.28	0.03	-0.06	0.01	-0.13	-0.49	-0.63

This process should also be able to eliminate the variables which are themselves closely related, thus to some extent the linearity of relationship between independent variables and the probability of including multicollinearity variables may also be reduced.

i. THEORETICAL MODEL A

There are 10 variables in this model and there are two measures for x12 and x5 stipulated in Chapter 8. Variables x18, x5a, x16, x12a, x12b, x5b, x1, x17 and x7 are correlated and the correlation is shown in Table 9.1a. Correlations which are higher than 0.8 are between x5a and x5b; x12a and x12b; x12a and x1. PCA for all 9 variables (Table 9.2a) shows that x5a and x12b have high latent vectors at latent roots 0.060 and 0.100 respectively. These two variables are now removed from the model.

This mean that for variable x5, the measure of x5b will be used, while for variable x12, measure x12b will be used. Since x12a is also highly correlated with x1, the probability of it being a multicollinear variable also exist and its removal is justified. 10 variables remained, the removal of the two measures do not effect the theoretical model.

ii. THEORETICAL MODEL B

There are 8 variables in this model but there is no variable which have two measures. For the purpose of weeding out the problem of linearity and to a certain extent multicollinearity, the same process as above will be carried out. Variables x18, x13, x7, x15, x8, and x1 are correlated and the correlation is shown in Table 9.1b. Correlation which is higher than 0.8 are between x15 and x1. PCA for all 6 variables (Table 9.2b) shows that at latent roots 0.050 variable x15 have a high latent vector. This variable is now removed from the model. Another variable x13 also has high latent vector at latent roots 0.118 but correlations with other variables are not too high and x13 is thus not removed.

This mean that the variable x1 also contain basically the same information as variable x15. If x1 is significant during model selection then x15 will have to be interpreted accordingly. Thus only 7 variables will be used and one variable has been removed from the theoretical model for the time being.

iii. THEORETICAL MODEL C

Theoretical model C contains 11 variables and there are two measures for x12 and x5. Variables x5b, x12a, x3, x5a, x7, x1, x6, x2 and x12b are correlated and the correlation is shown in Table 9.1c. Correlation which is higher than 0.8 is between x5a and x5b. PCA for all 9 variables (Table 9.2c) shows that x5a has a high latent vector at latent root 0.001. This variable is now removed from the model.

This mean that for variable x5, the measure of x5b will be used, while for variable x12, the extent of the linearity in relationship is not very strong and the latent vector is only high at 0.217. As such variable x12 measures will be split into two variables. Thus 12 variables will be used and the addition of one variable will effect the theoretical model only if the additional variable is significant after the model selection process.

iv) THEORETICAL MODEL D

Theoretical model D contains 10 variables and there are two measures for x12. Variables x5, x12a, x3, x7, x6, x2 and x12b are correlated and the correlation is shown in Table 9.1d. No correlation higher than 0.8 is detected. Since no variable warrants deletion the PCA done for all 7 variables (Table 9.2d) is not used, although variable x3 has high latent latent vector at latent root 0.154.

This mean that for variable x12, the extent of the linearity in relationship is not very strong and the latent latent vector is only high at latent root 0.346. As such variable x12 measures will also have to be split into two variables as in theoretical model C. Thus 11 variables will be used and the addition of one variable will effect the theoretical model only if the additional variable is significant after the model selection process.

v. THEORETICAL MODEL E

Theoretical model E contains 10 variables and there are three measures for x5. Variables x13, x7, x1, x15, x8, x11, x5a, x5b and x5c are correlated and the correlation is shown in Table 9.1e. Correlation which are higher than 0.8 are between x5a,x5b and x5c. PCA for all 9 variables (Table 9.2e) shows that at latent roots 0.039 and 0.114, x5b and x5a has high latent latent vectors and thus both measure will be deleted. Thus variable x5 will be measured through x5c. Thus 10 variables will be used and the theoretical model is not change.

9.4.2 MODEL FITTING FOR THE PURPOSES OF MODEL CHECKING -

Each model is then fitted to the data using the selected variables for the purpose of other tests and checks to be done. A summary of the results of the initial model fitting is in Appendices E.1-E.5. The null model (which is the model without the influence of variables included) which measure the total variation in the data of all model shows a high mean deviance residual for all models: 14.723 (A), 24.84 (B), 11.099 (C), 6.269 (D) and 6.067 (E). After each fitting of a theoretical model the checks in the following setions are made.

FIGURE 9.1(A)
THEORETICAL MODEL A
CHECKING LINEARITY

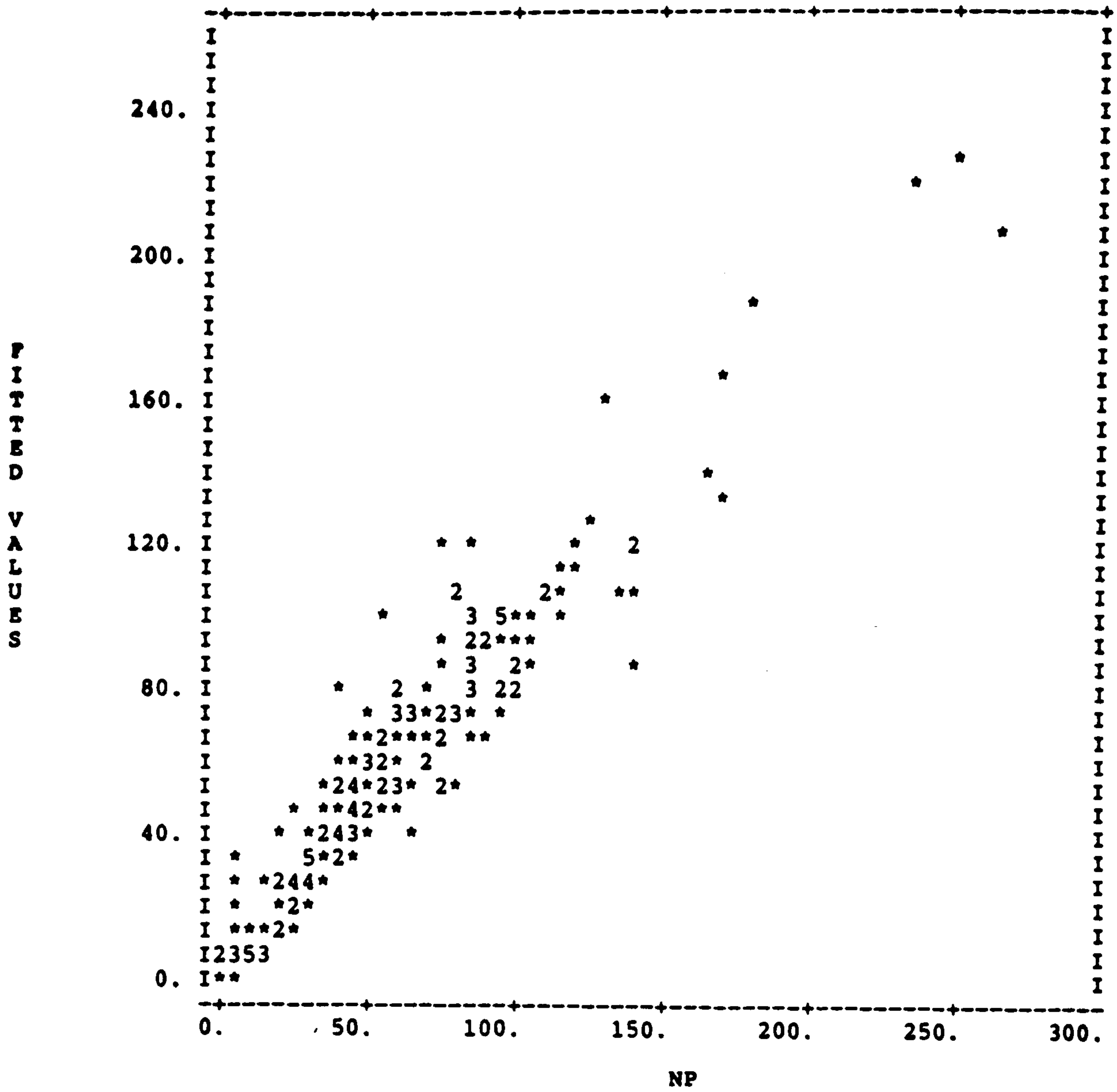


FIGURE 9.1(B)
THEORETICAL MODEL B
CHECKING LINEARITY

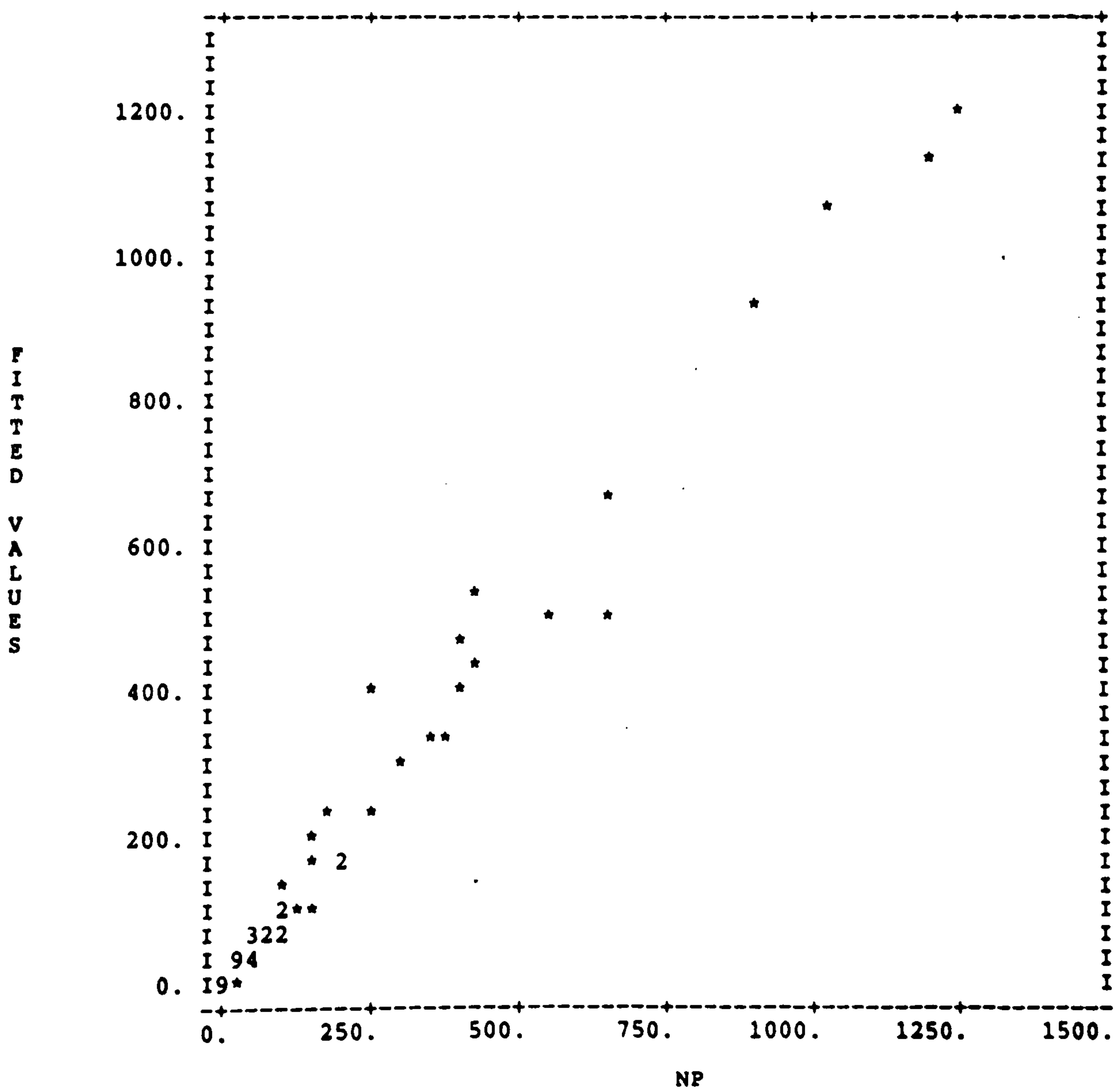


FIGURE 9.1(C)
CHECKING LINEARITY
THEORETICAL MODEL C

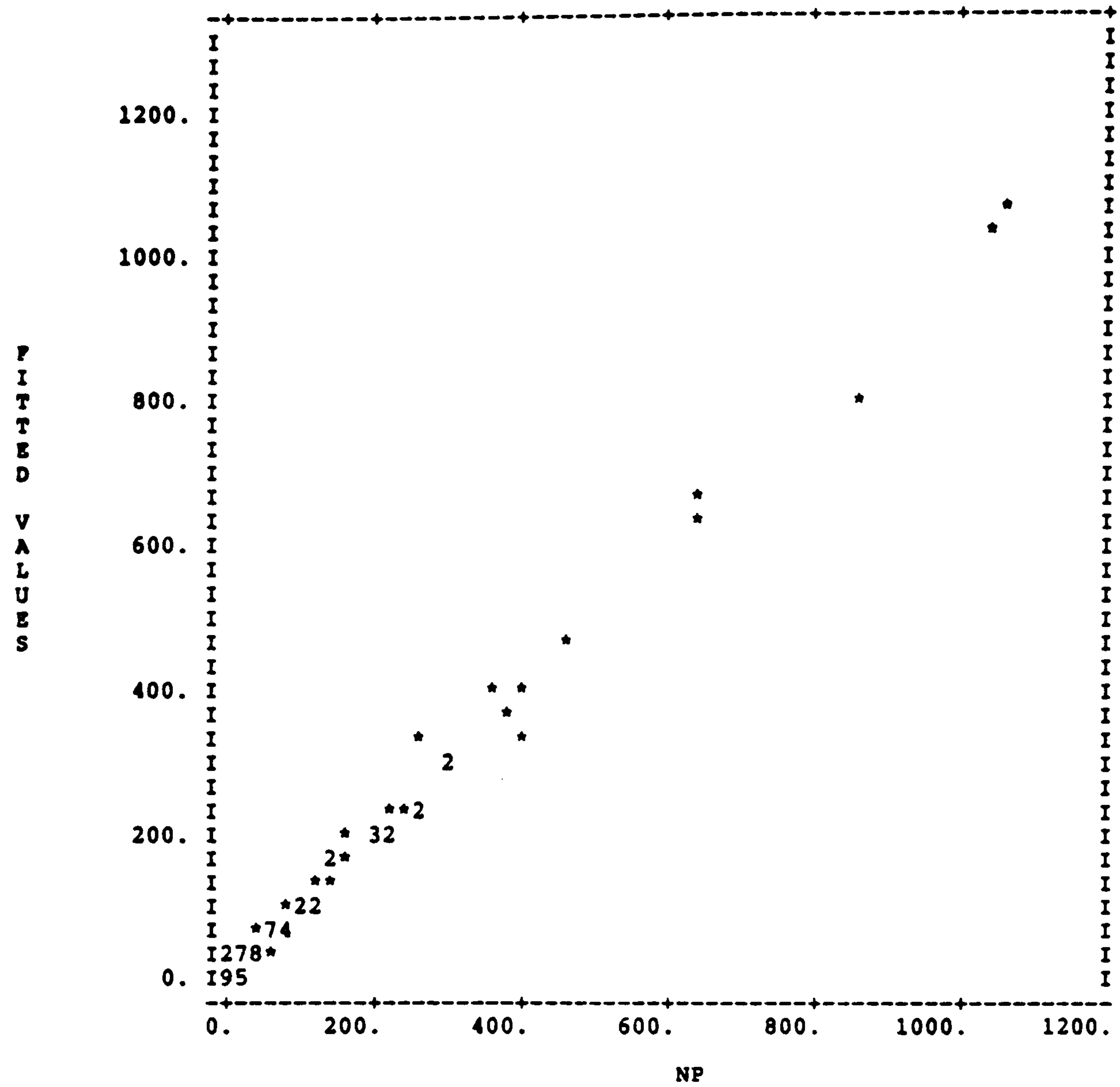


FIGURE 9.1(D)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

CHECKING LINEARITY

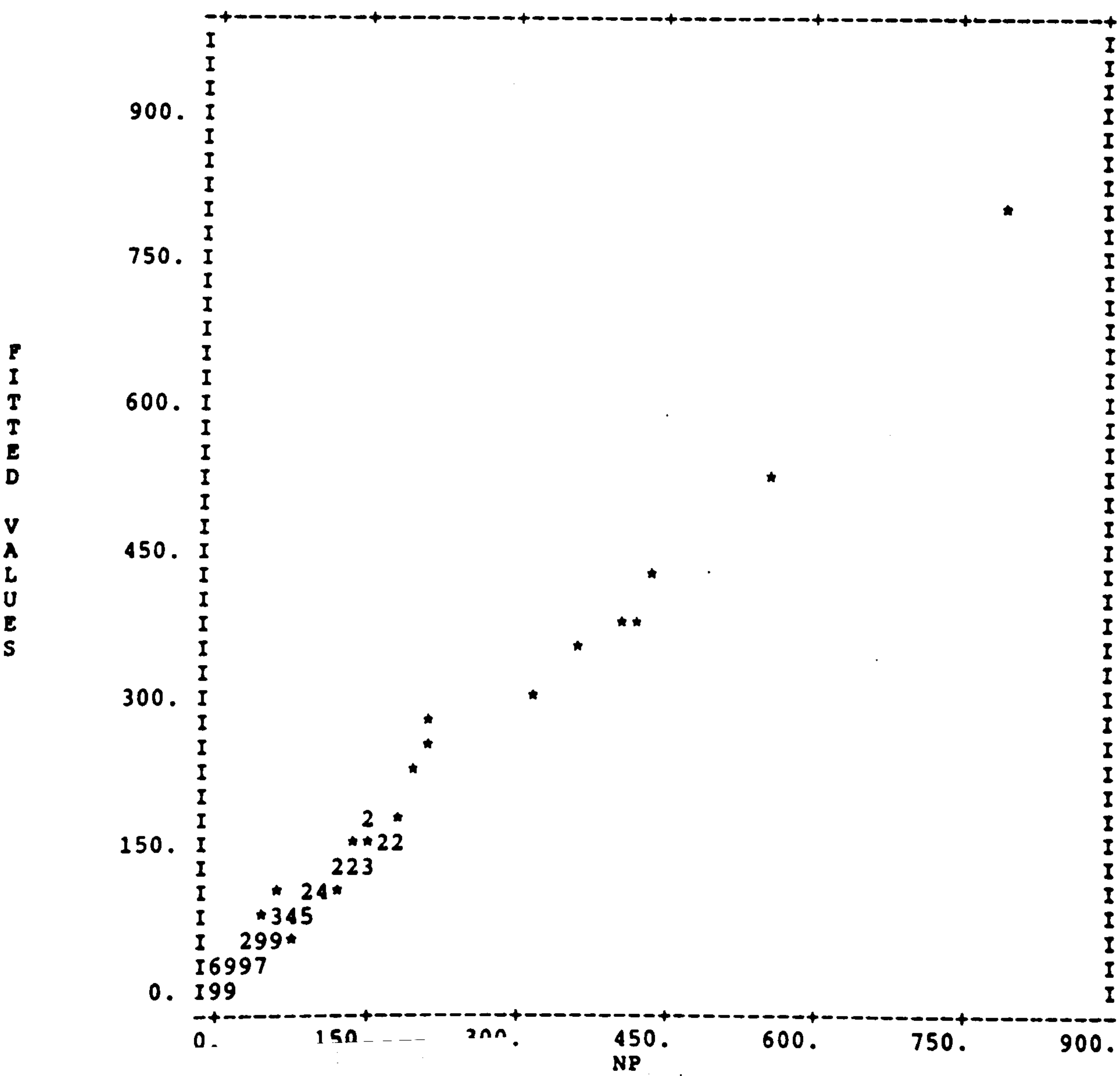
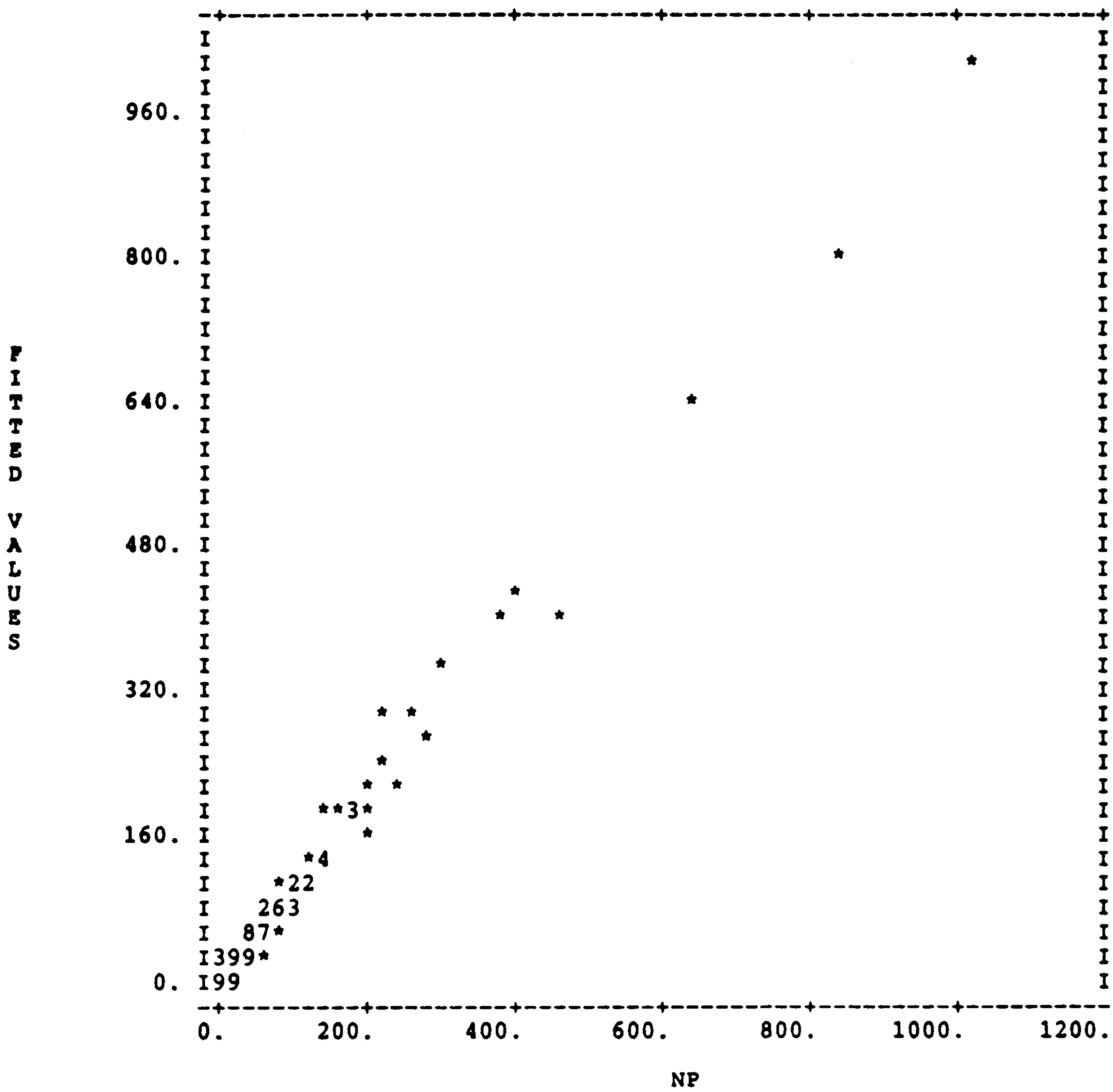


FIGURE 9.1(E)
CHECKING LINEARITY
THEORETICAL MODEL E



9.4.3 TEST FOR SUITABLE SCALE FOR CHECKING LINEAR - RELATIONSHIP WITH RESPONSE VARIABLE.

The linear classical model was developed to approximate a linear function between a response variates and covariates. Linear modelling thus made a critical assumptions in linearity of relationship between variates and covariates. Theoretically a linear relationship is assumed for most relationships especially when the nature of the relationship is certainly unknown, although the relationship may be far from linear. However the aim is not to construct a mathematical alrgorithm of the relationship between variates and covariates but rather using a predefined statistical algorithm to help in the identification of significant covariates and obtaining the best subset from a parsimonous model, the linearity assumptions is sufficed. Categorical and ordinal variables usually show non-linearity, however when symptoms of non-linearity exist covariates and even variates may be transformed into some other functions. Among the common one are the common log, square root, square, reciprocal to ensure linearity is achieved. Box- Cox transformation is a useful tool for suggesting transformation of the response variable. Box and Tidwell suggested a similar method to be applied for explanatory variables (329).

GLM in actual fact is not strictly linear because of the introduction of the link function, which transforms the response variate. A plot of fitted values of the response variate versus the response variate will show that it is to some extent curvilinear (Figures 9.1(a)-(e). Thus to some extent, the non-linearity of relationship is taken care of in GLM.

In classical linear models, the scale of measurement for explanatory variable is an important aspect of model checking. A good scale has to combine constant variance and approximate normality of errors with additivity of systematic effects (320). The scaling problems are largely removed by applying GLM because normality and constant variance are not required. Variable scale has still to be checked for signs of non-linearity in the relationship between the response and independent variables. Non-linearity can be inspected by visual inspection of standardized residual vs standardized values of the predictor variables. Lack of overall shape of the plot may necessitate the testing using the above method. McCullagh and Nelder (330) suggested two forms of checking; graphical or statistical. In view of the simplicity of graphical check, it was done first, to be followed by statistical tests if the need arise. This can be done by creating Generalised Partial Residual (GPR) plot against an independent variable. If any signs of transformation is required, the pattern should show the need. GPR is defined as:-

---

GPR = z-flp+flamda(x)

where z = adjusted dependant variable; flp = fitted linear predictor for a model including x; flamda = the regression coefficient for x; x = the independent variable where z for binomial model with logit function (M and C pg 80) is:-

$$z = lp + \frac{y-n(p)}{n(p(1-p)}$$

where lp = linear predictor; n = binomial total for y; y = a unit of observation productive p = proportion of productive from n.

The FIT directive was activated specifically to check this one at at time for each quantitative variable. The residual plot against each independent variable for each theoretical model is done. Figures 9.2(a)-(g), 9.3(a)-(e), 9.4(a)-(h), 9.5(a)-(g) and 9.6(a)-(g) show satisfactory linear form of all the variables in all models, which do not suggest any need for transformation of scale. The statistical test is deemed unnecessary and the assumption of appropriate scale for quantitative variable is thus justified.

9.4.4 CHECKING THE LINK FUNCTION -

The link function is an important component of GLM and a satisfactory link function must be used. Plot of 'z-flp+flp' i.e. the Adjusted Dependent Variable against the Linear Predictor will be performed. The plot should show linearity. Appropriate transformation if needed can be

FIGURE 9.2(A)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

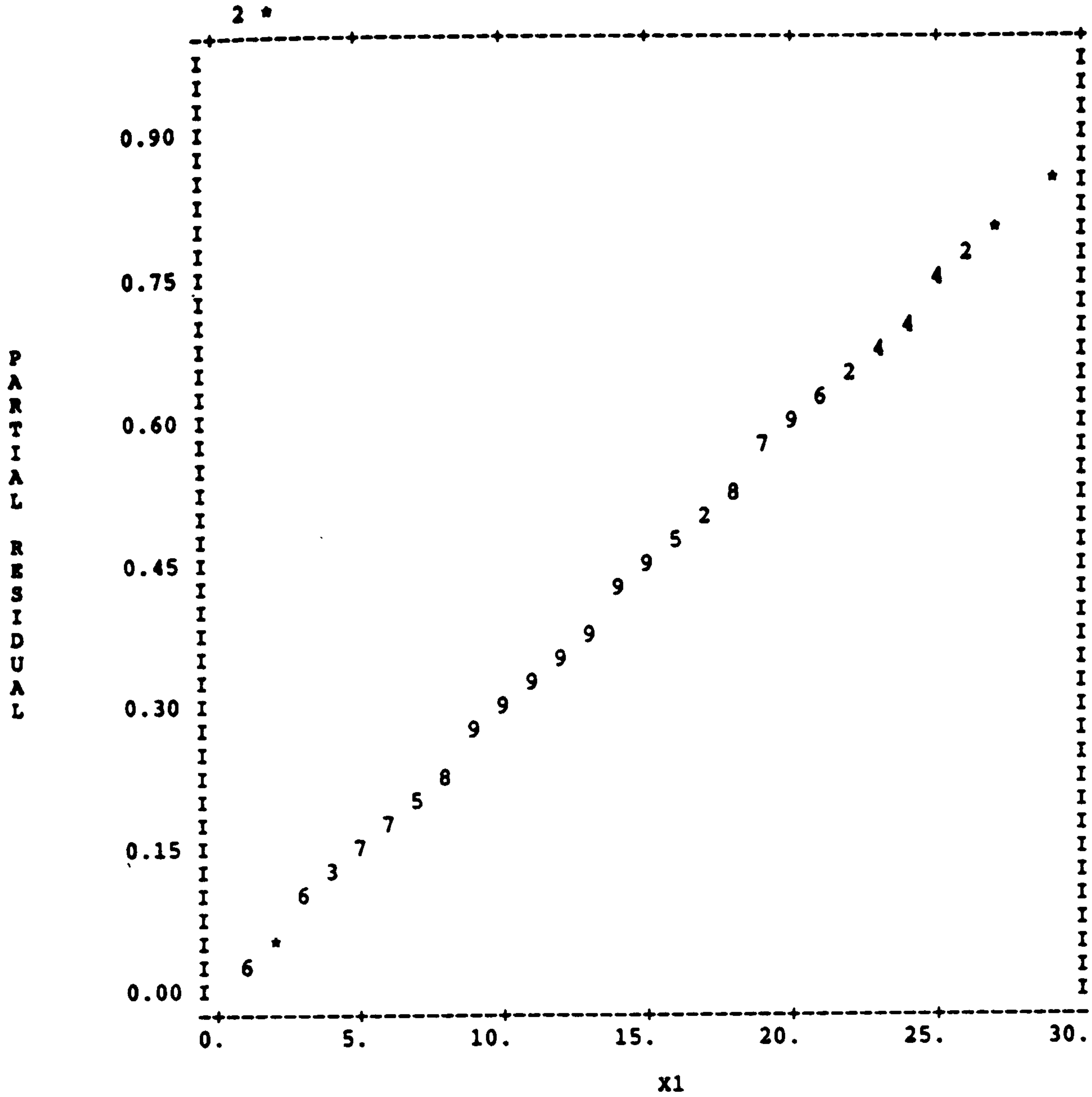


FIGURE 9.2(B)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

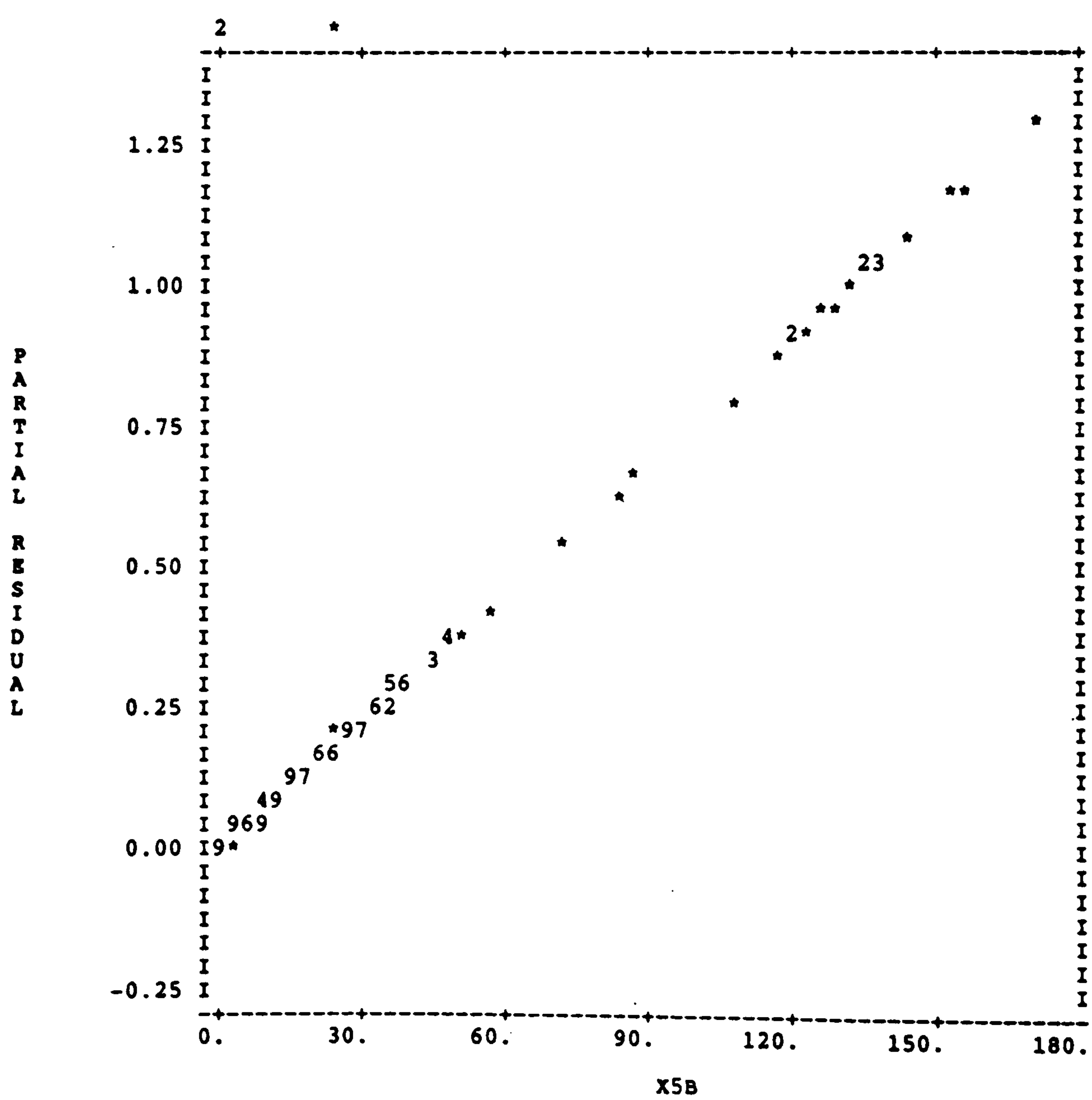


FIGURE 9.2(C)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

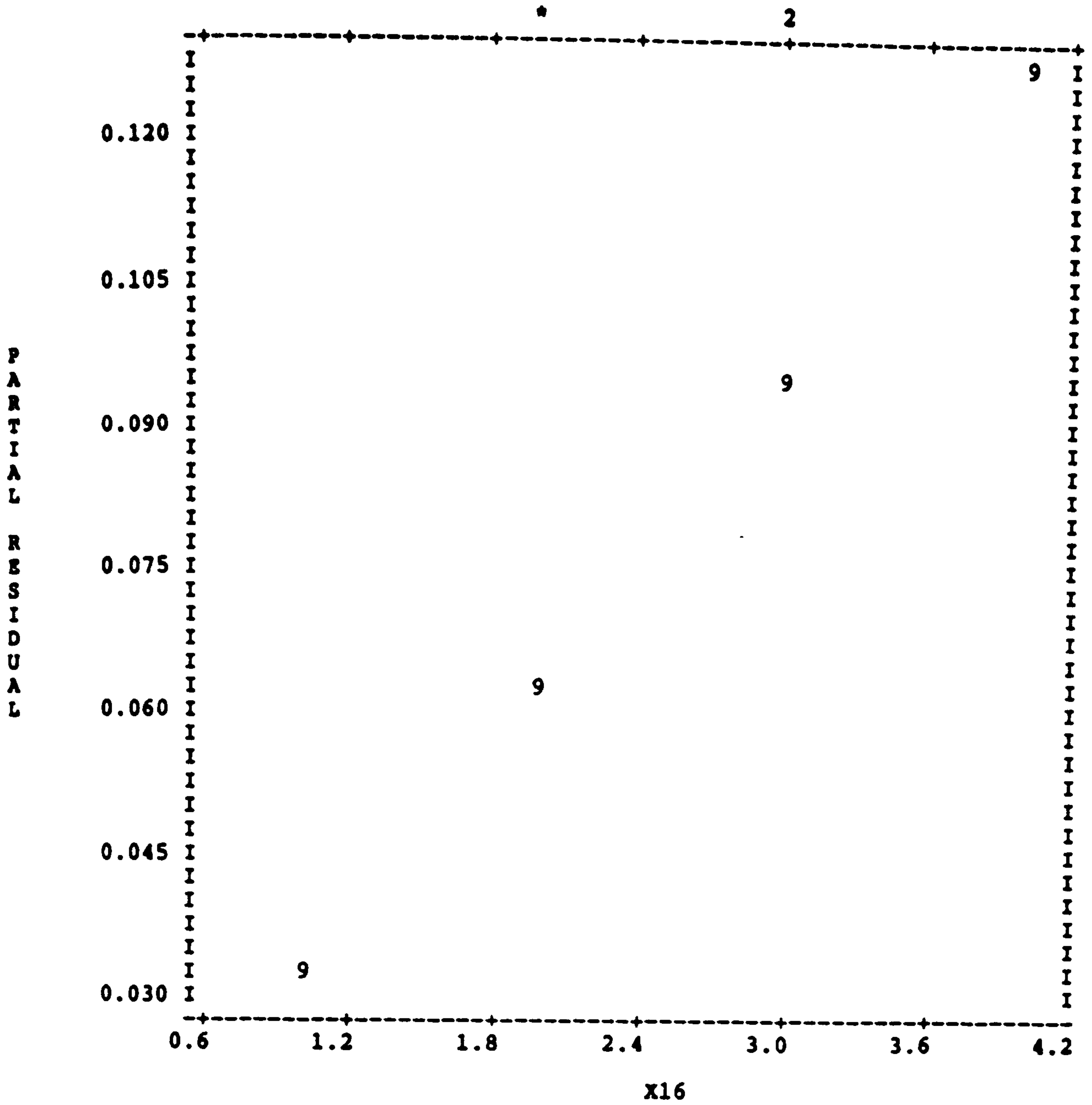


FIGURE 9.2(D)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

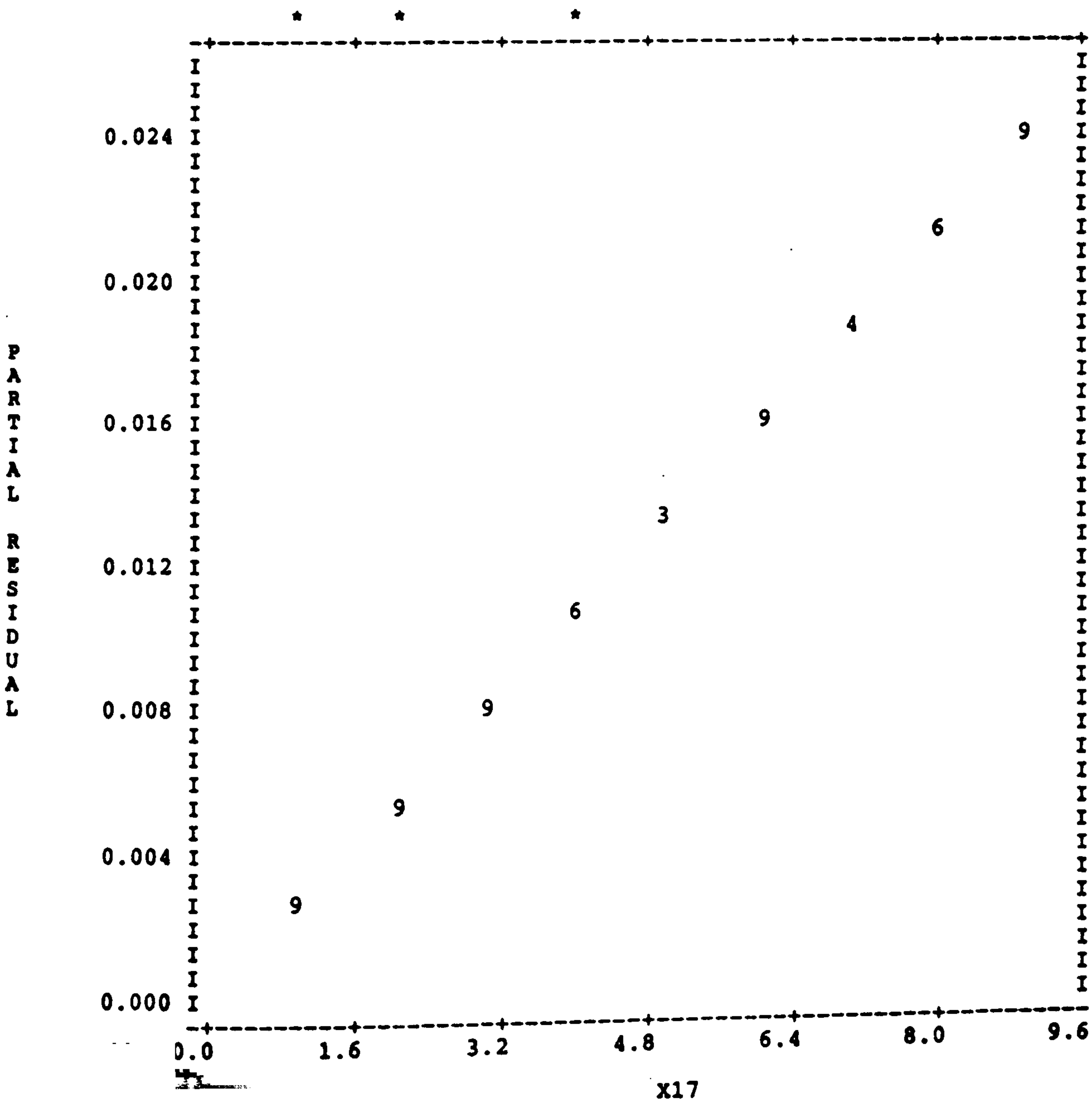


FIGURE 9.2(E)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

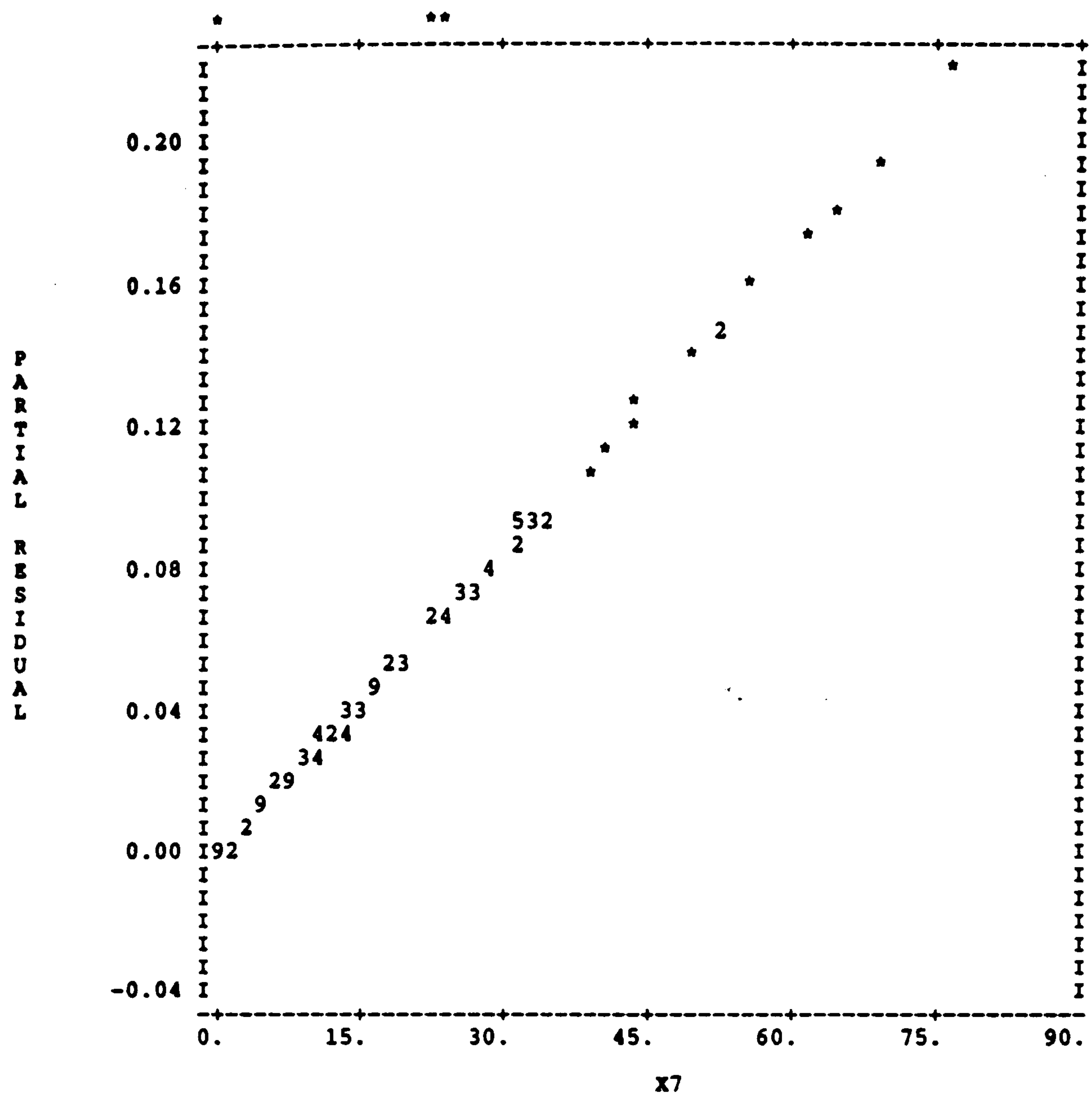


FIGURE 9.2(F)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

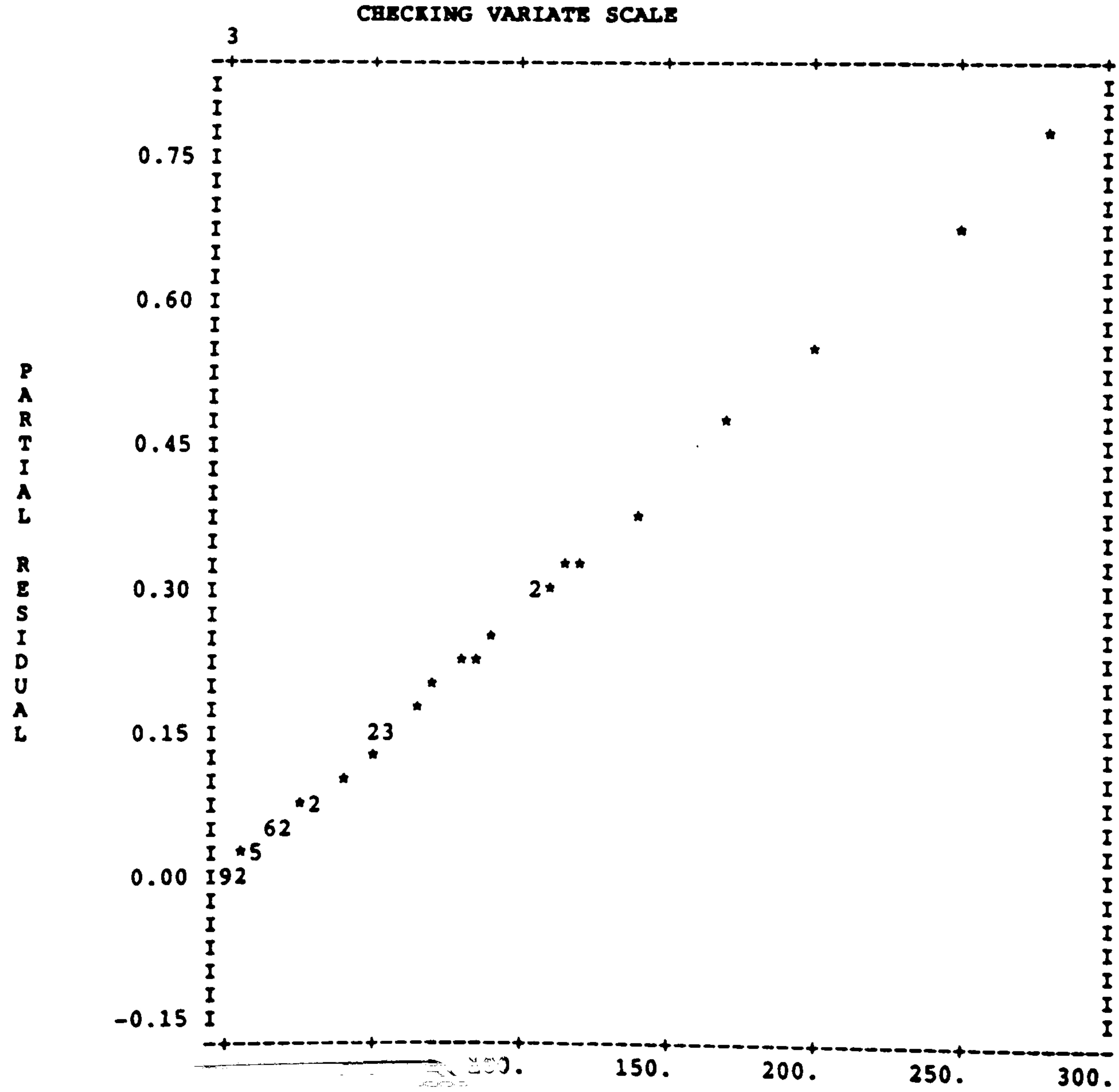


FIGURE 9.2(G)
THEORETICAL MODEL A
CHECKING VARIATE SCALE

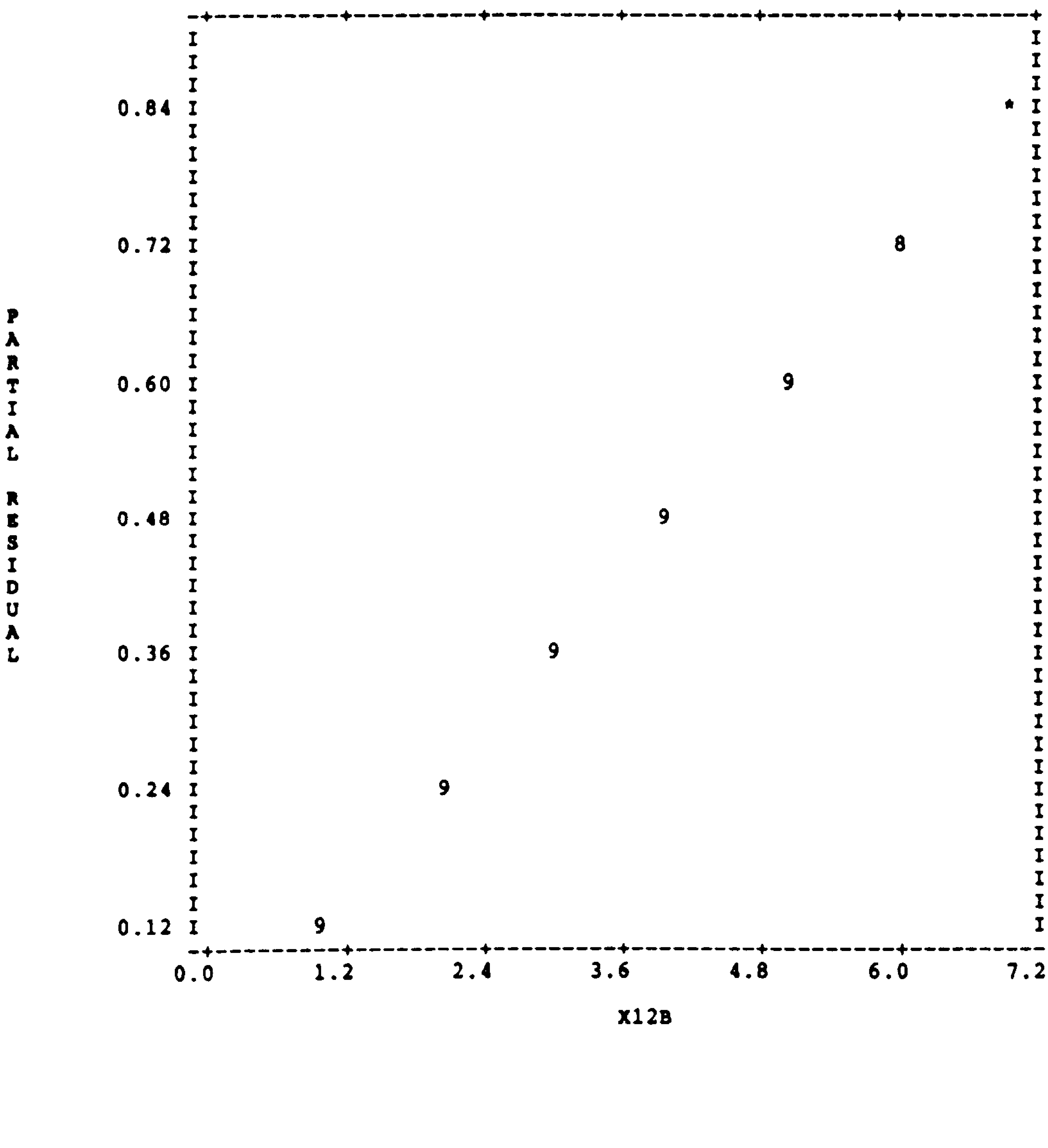


FIGURE 9.3(A)
THEORETICAL MODEL B
CHECKING VARIATE SCALE

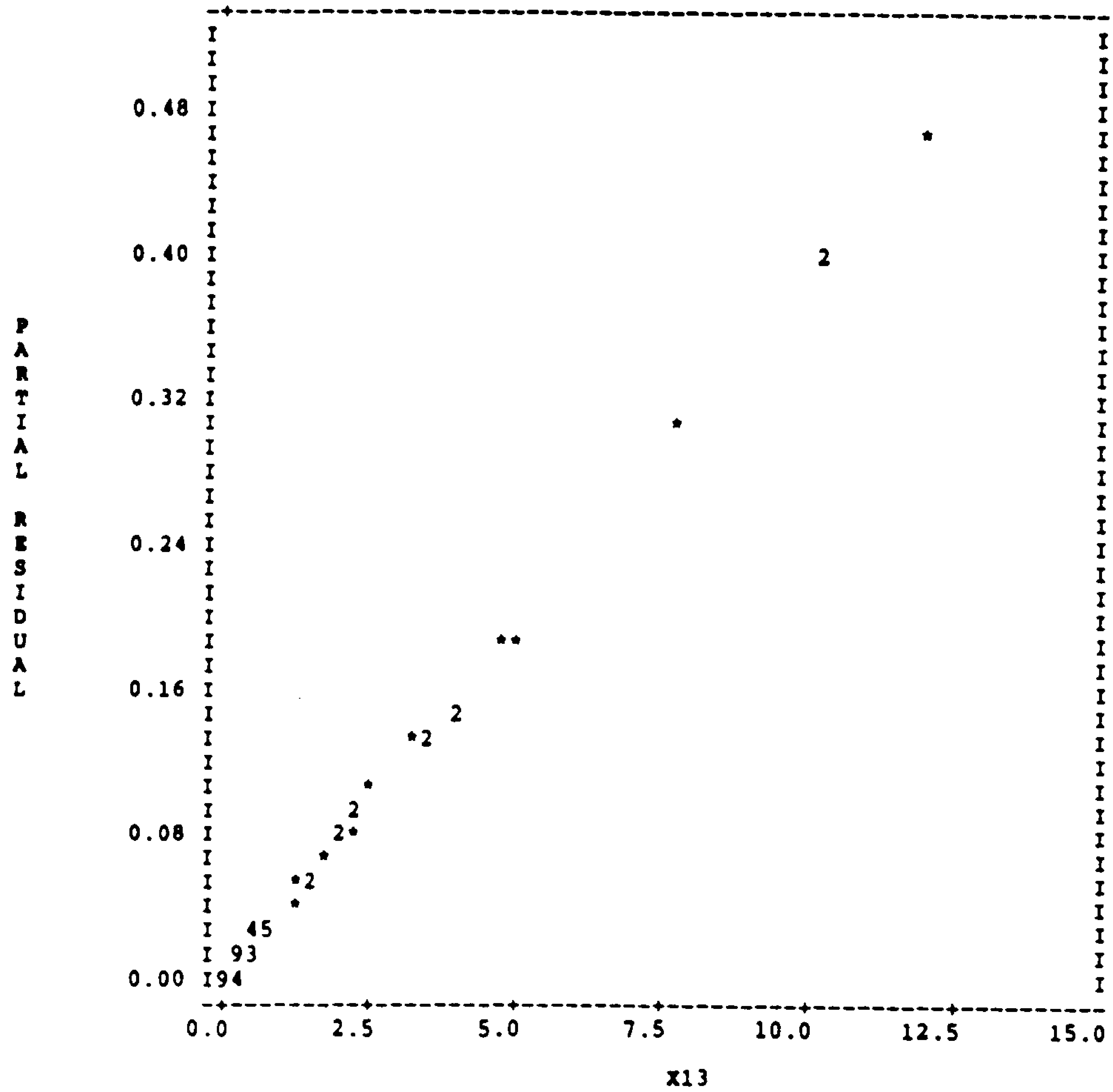


FIGURE 9.3(B)
THEORETICAL MODEL B
CHECKING VARIATE SCALE

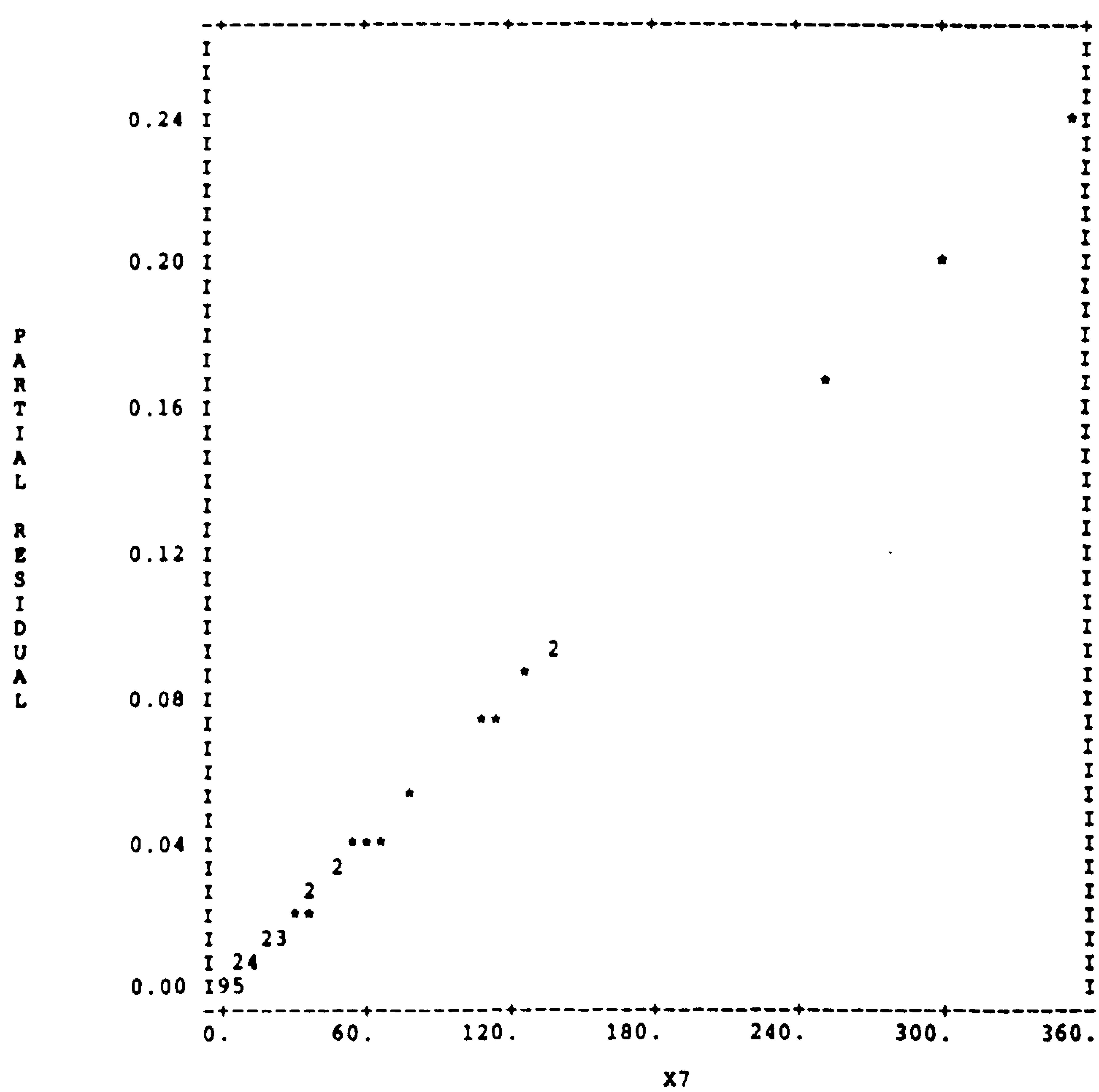


FIGURE 9.3(C)
THEORETICAL MODEL B
CHECKING VARIATE SCALE

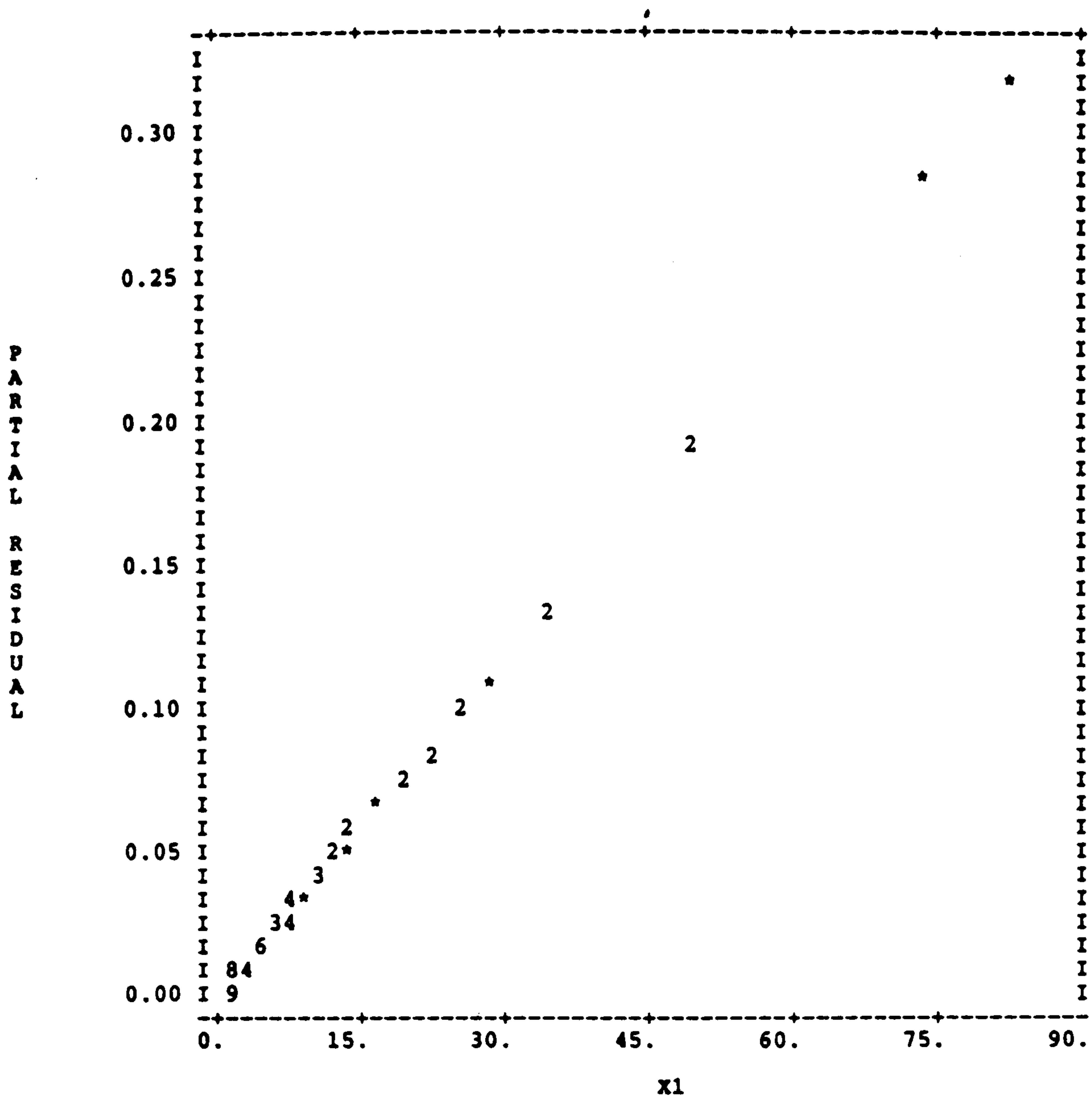


FIGURE 9.3(D)
THEORETICAL MODEL B
CHECKING VARIATE SCALE

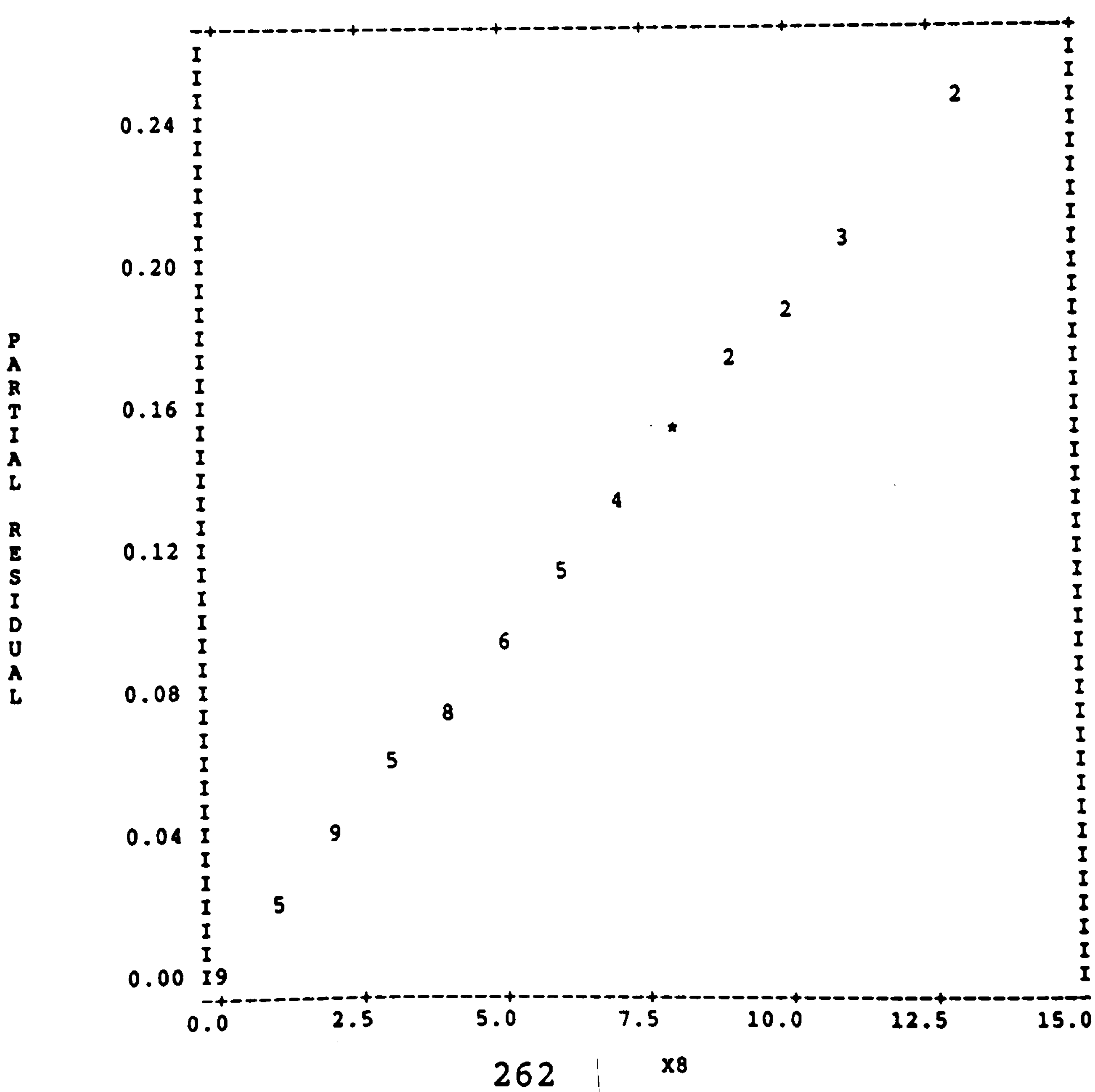


FIGURE 9.3(E)
THEORETICAL MODEL B
CHECKING VARIATE SCALE

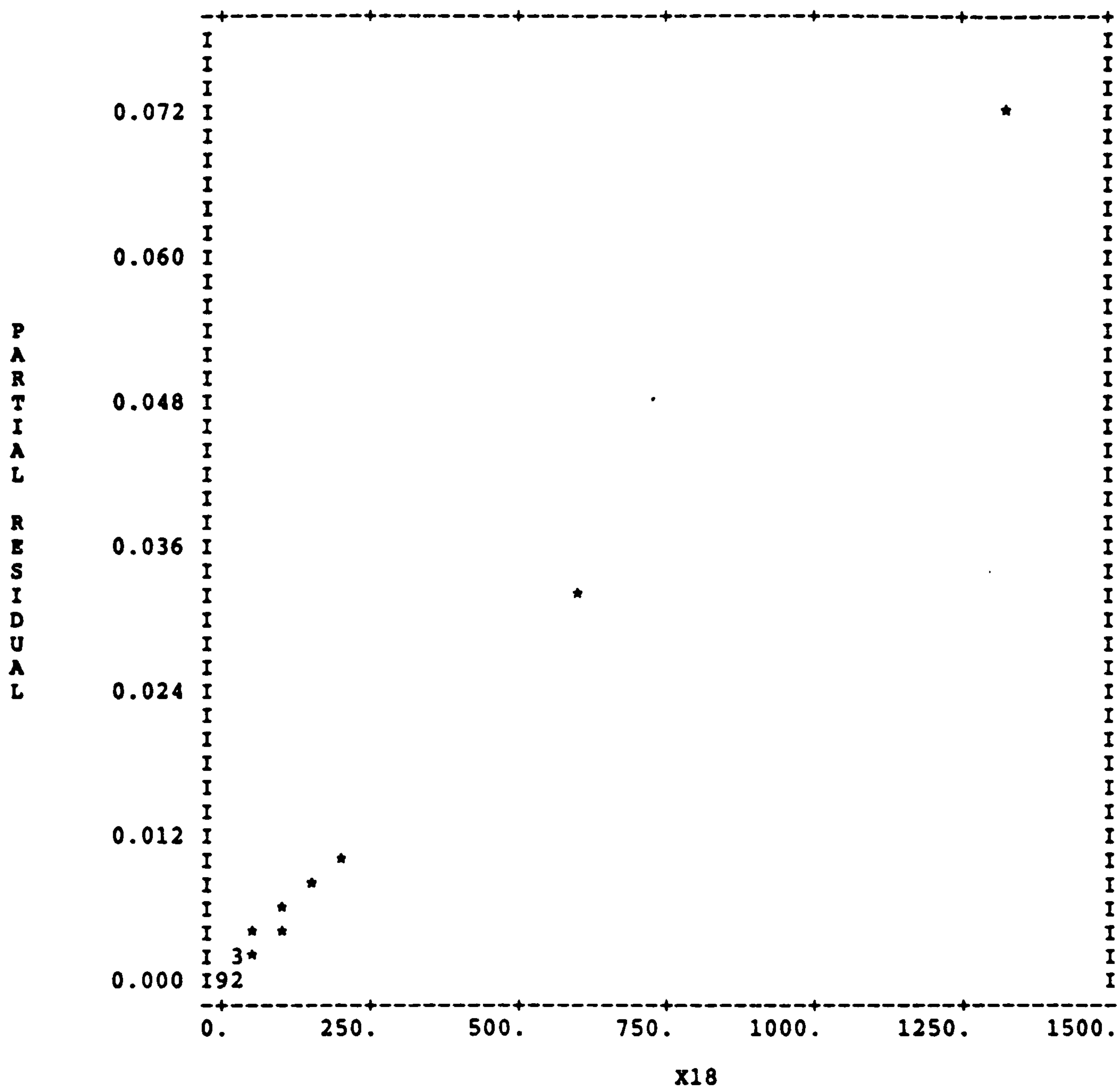


FIGURE 9.4(A)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

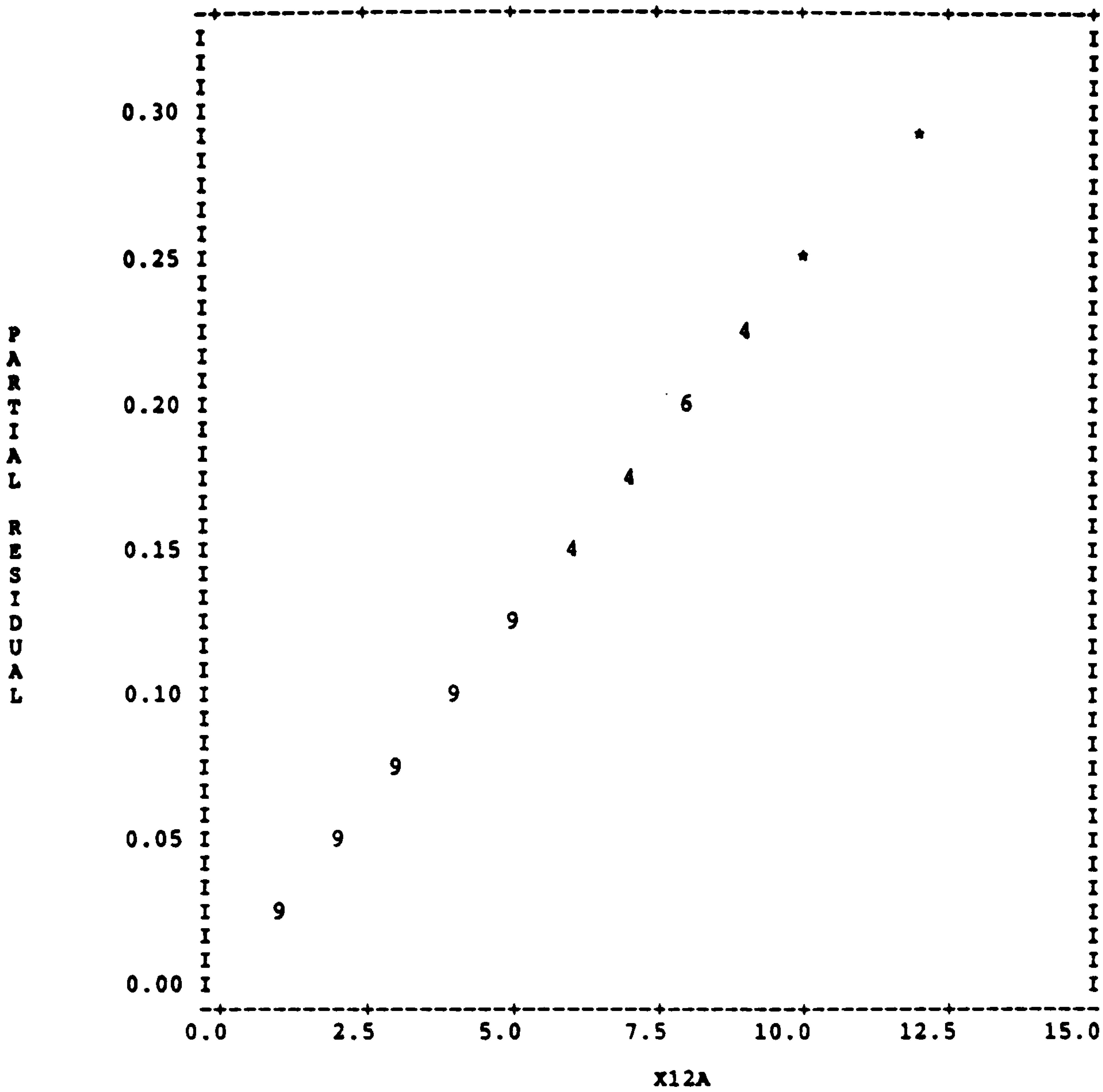


FIGURE 9.4(B)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

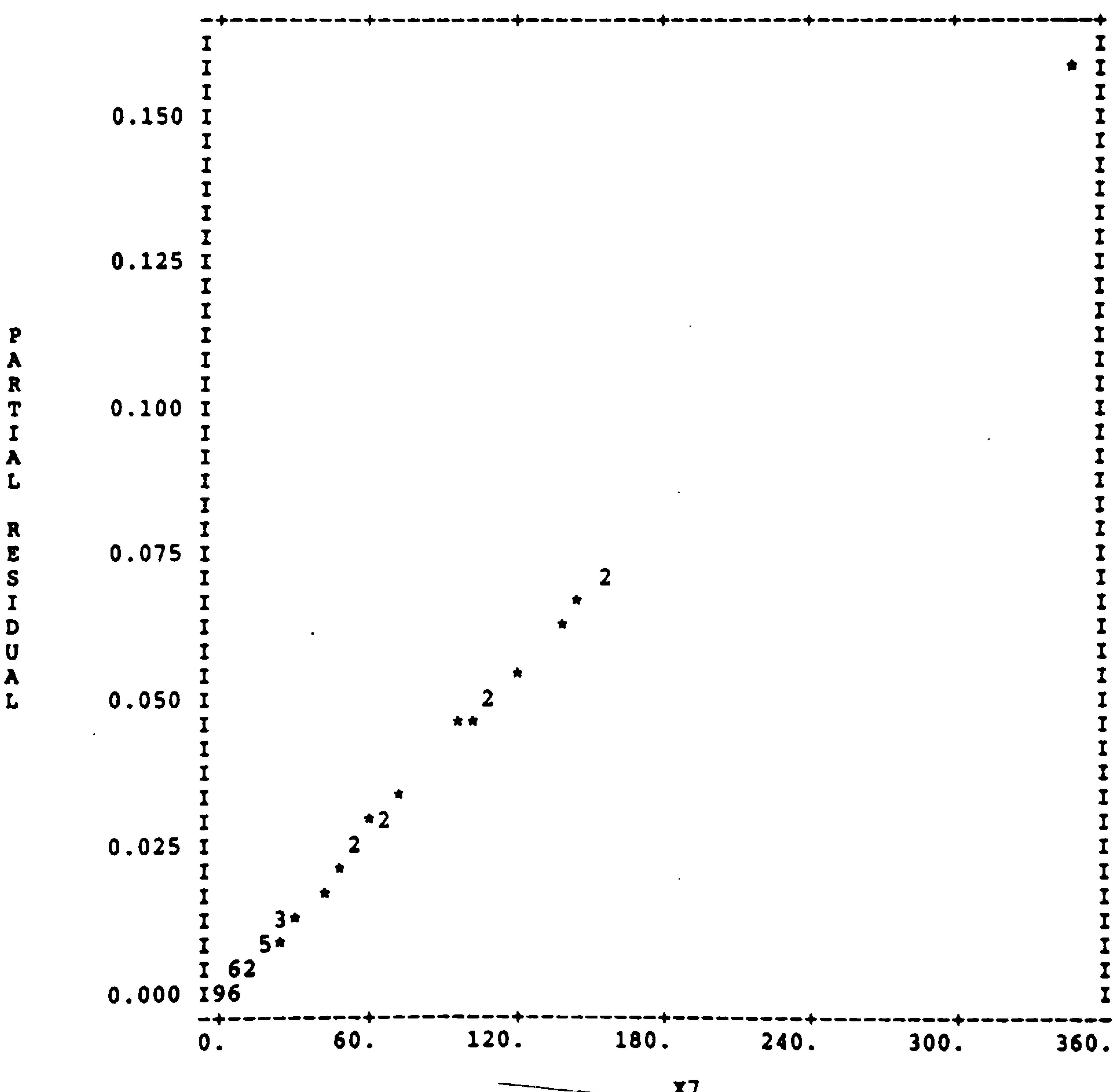


FIGURE 9.4(C)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

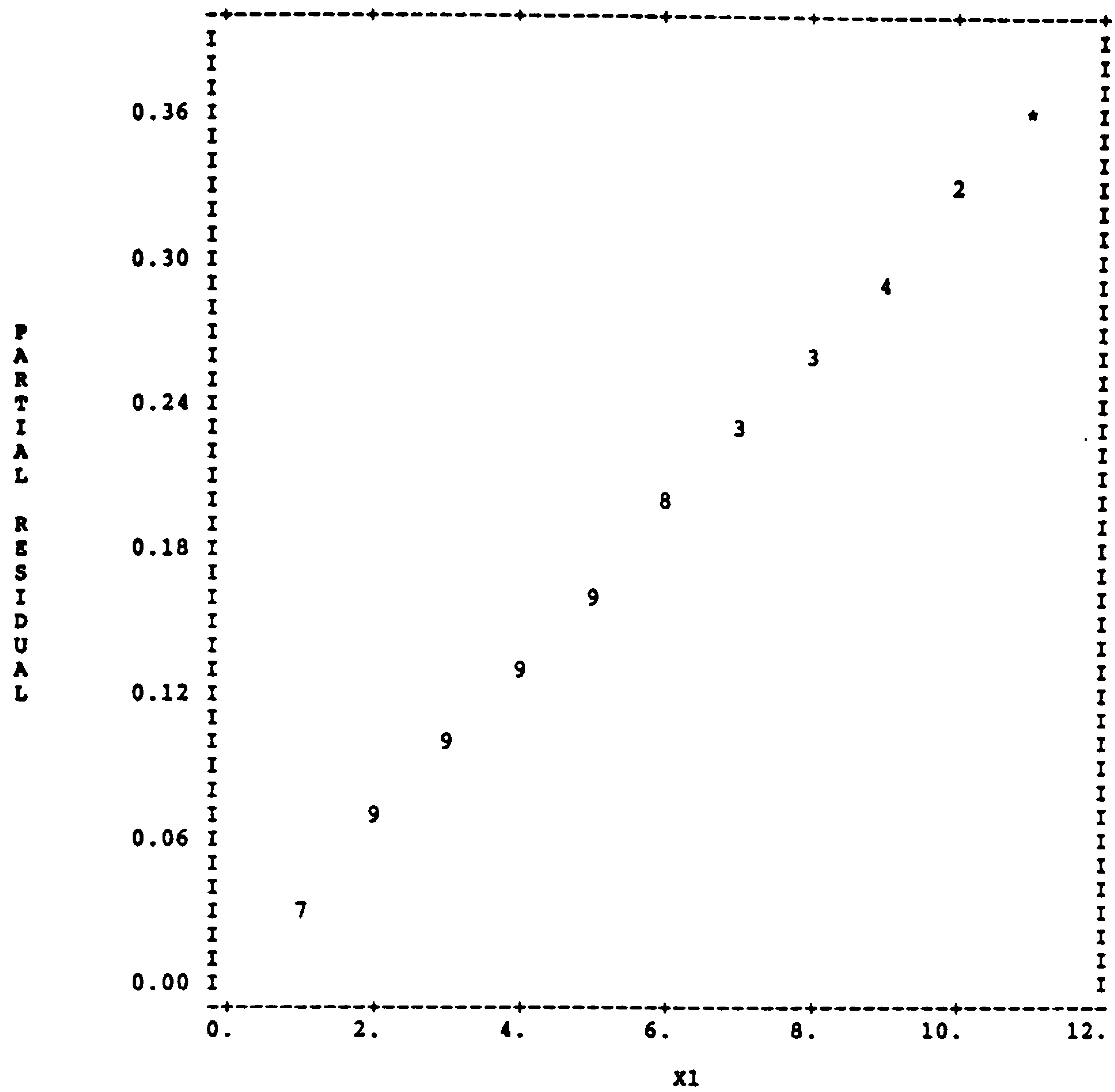


FIGURE 9.4(D)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

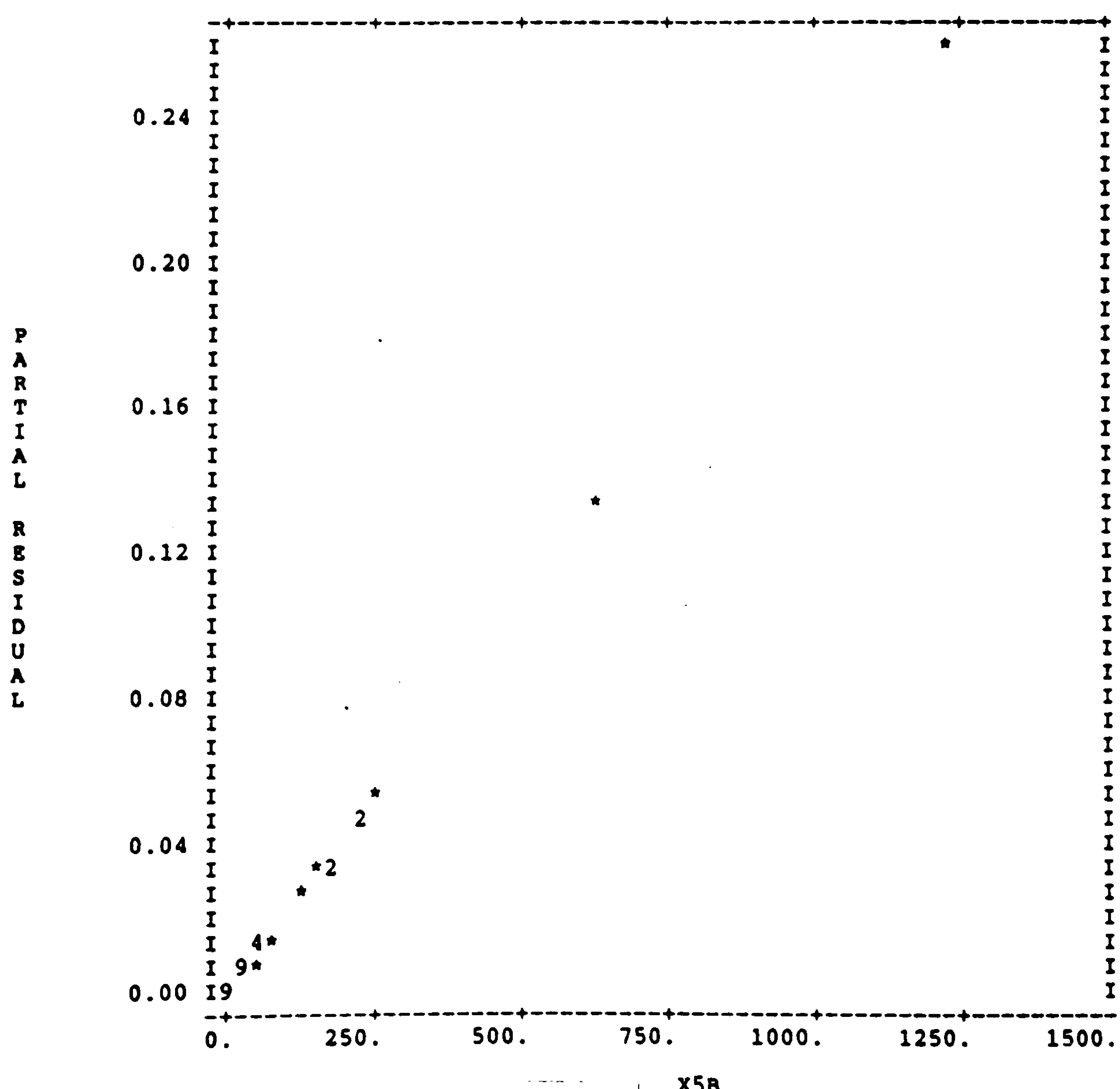


FIGURE 9.4(E)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

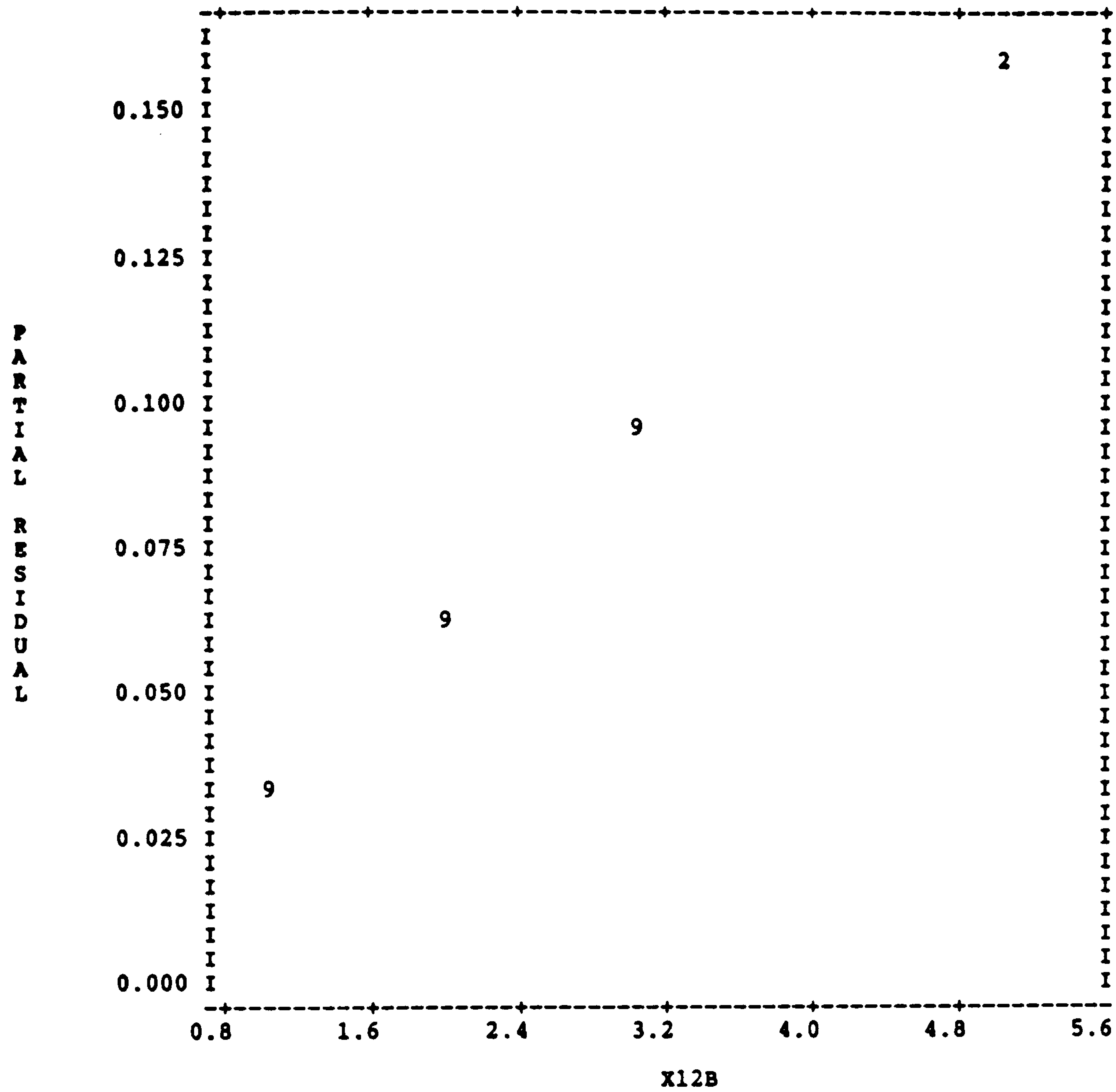


FIGURE 9.4(F)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

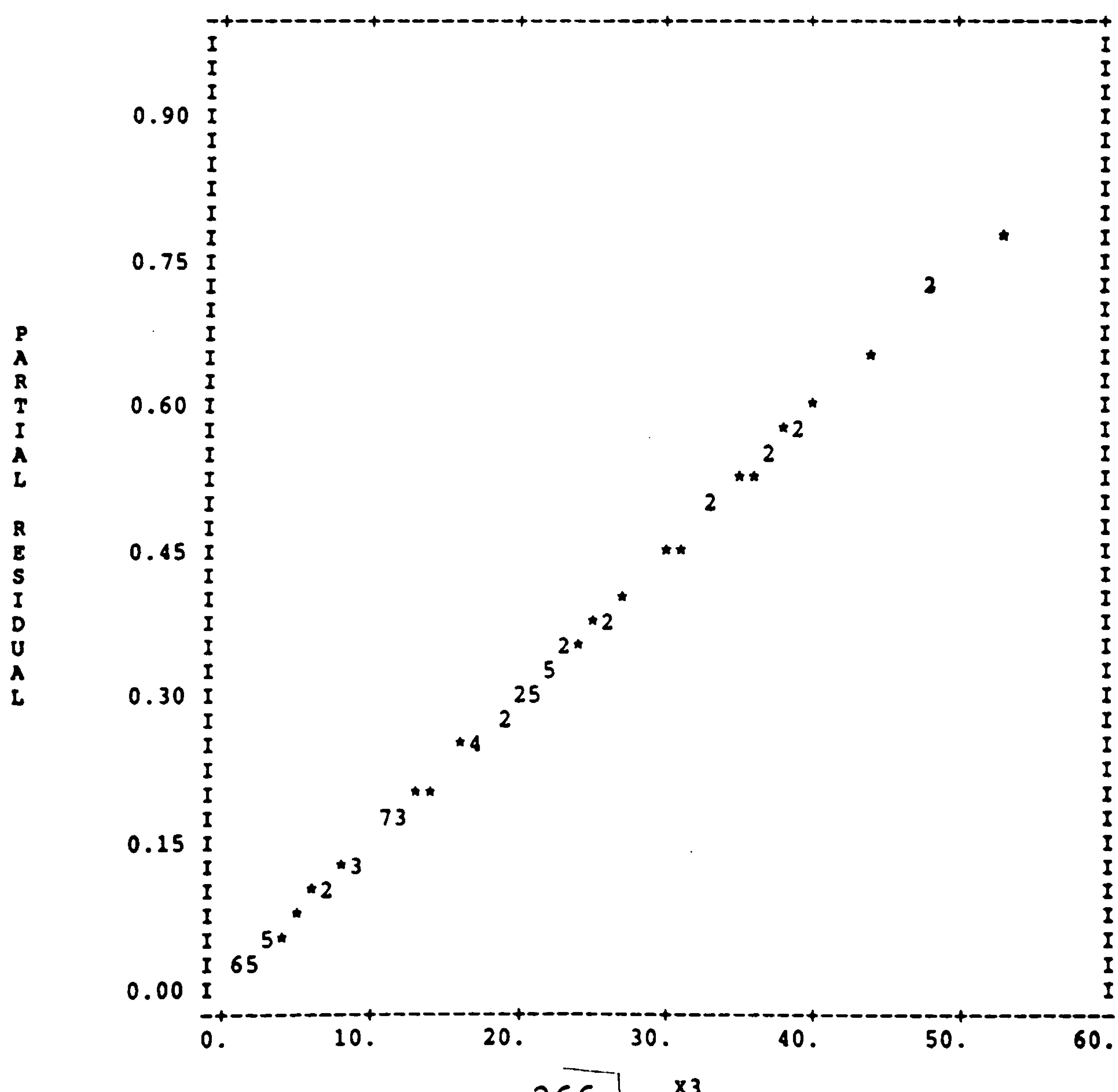


FIGURE 9.4(G)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

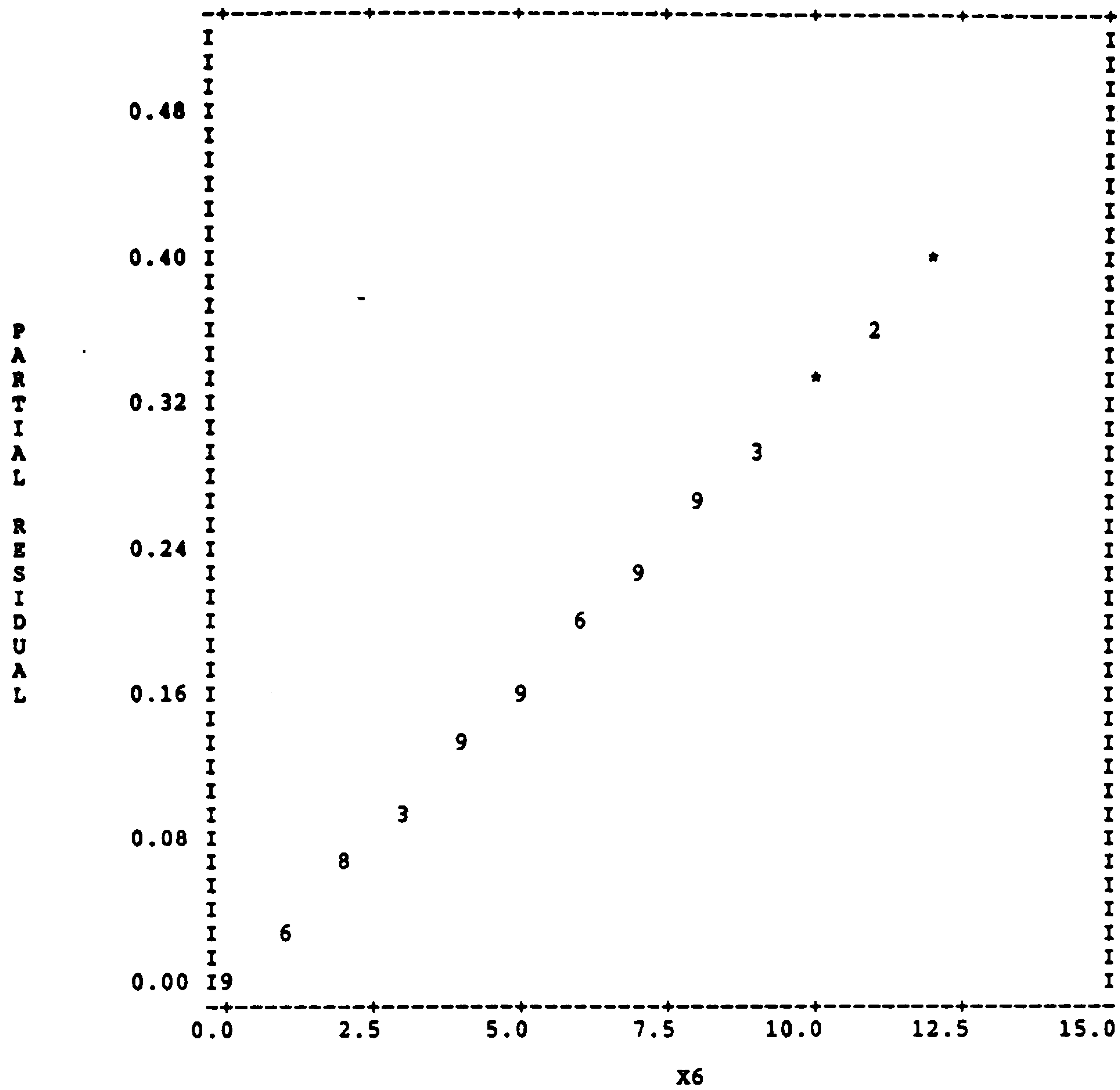


FIGURE 9.4(H)
CHECKING VARIATE SCALE
THEORETICAL MODEL C

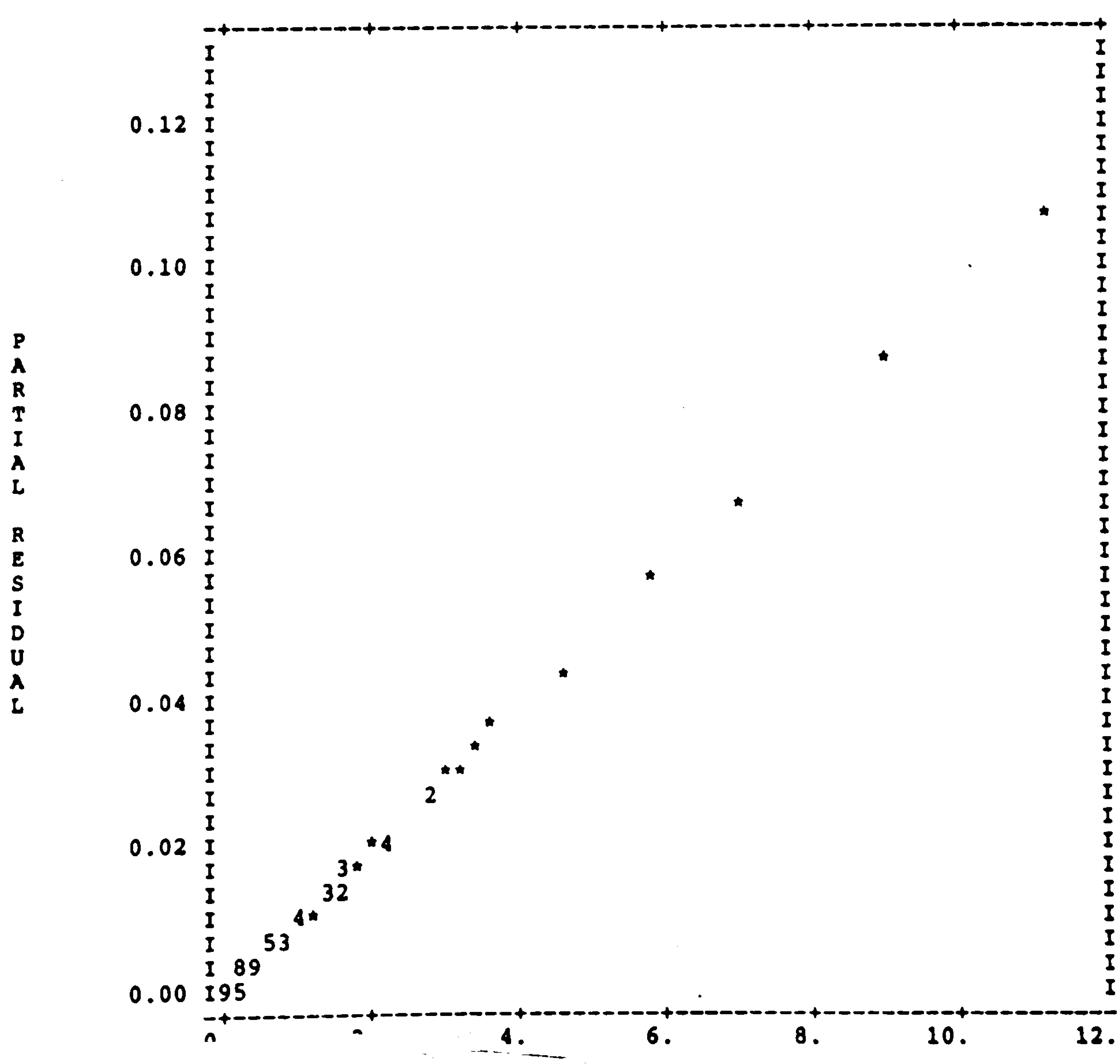


FIGURE 9.5(A)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

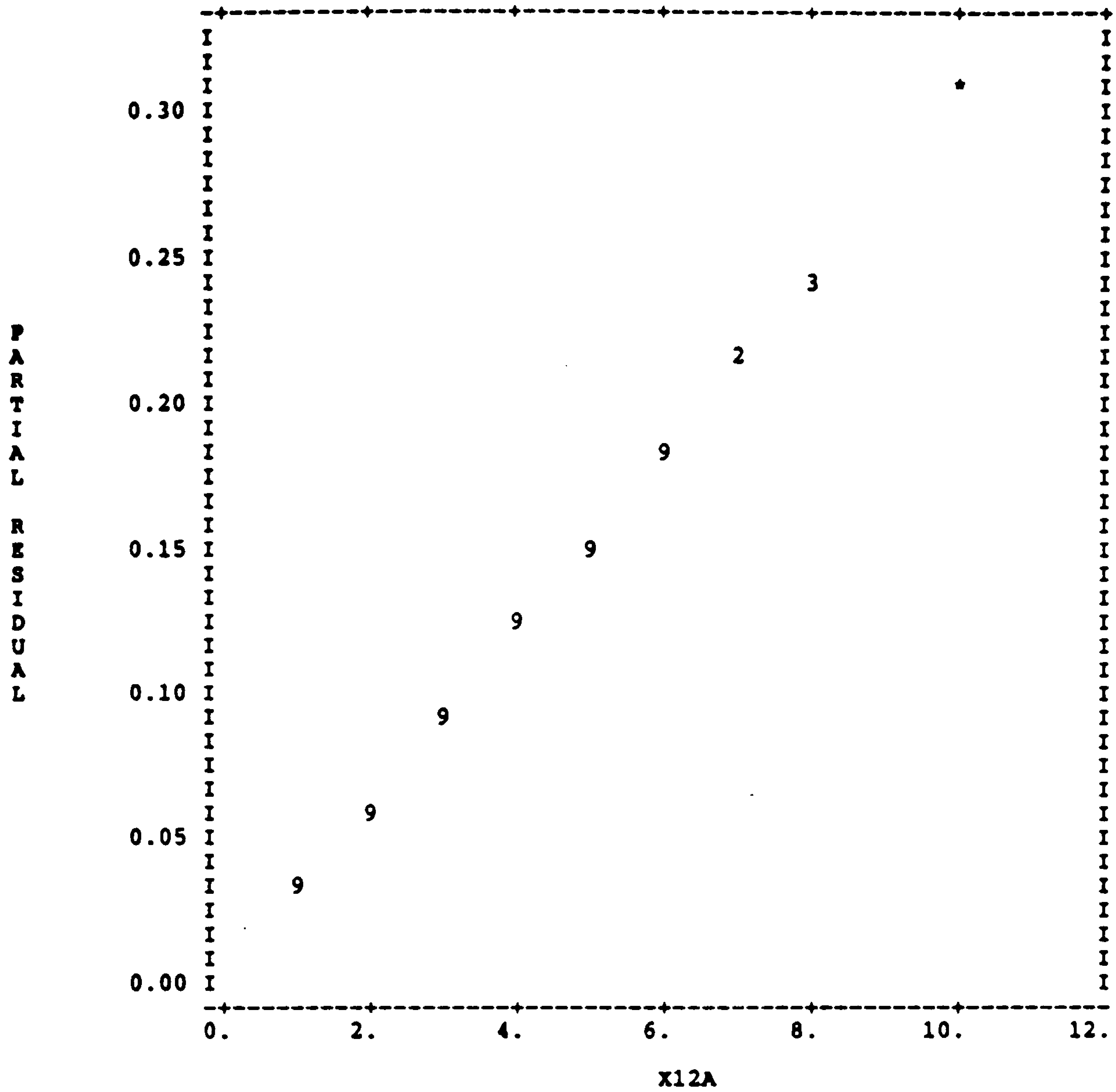


FIGURE 9.5(B)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

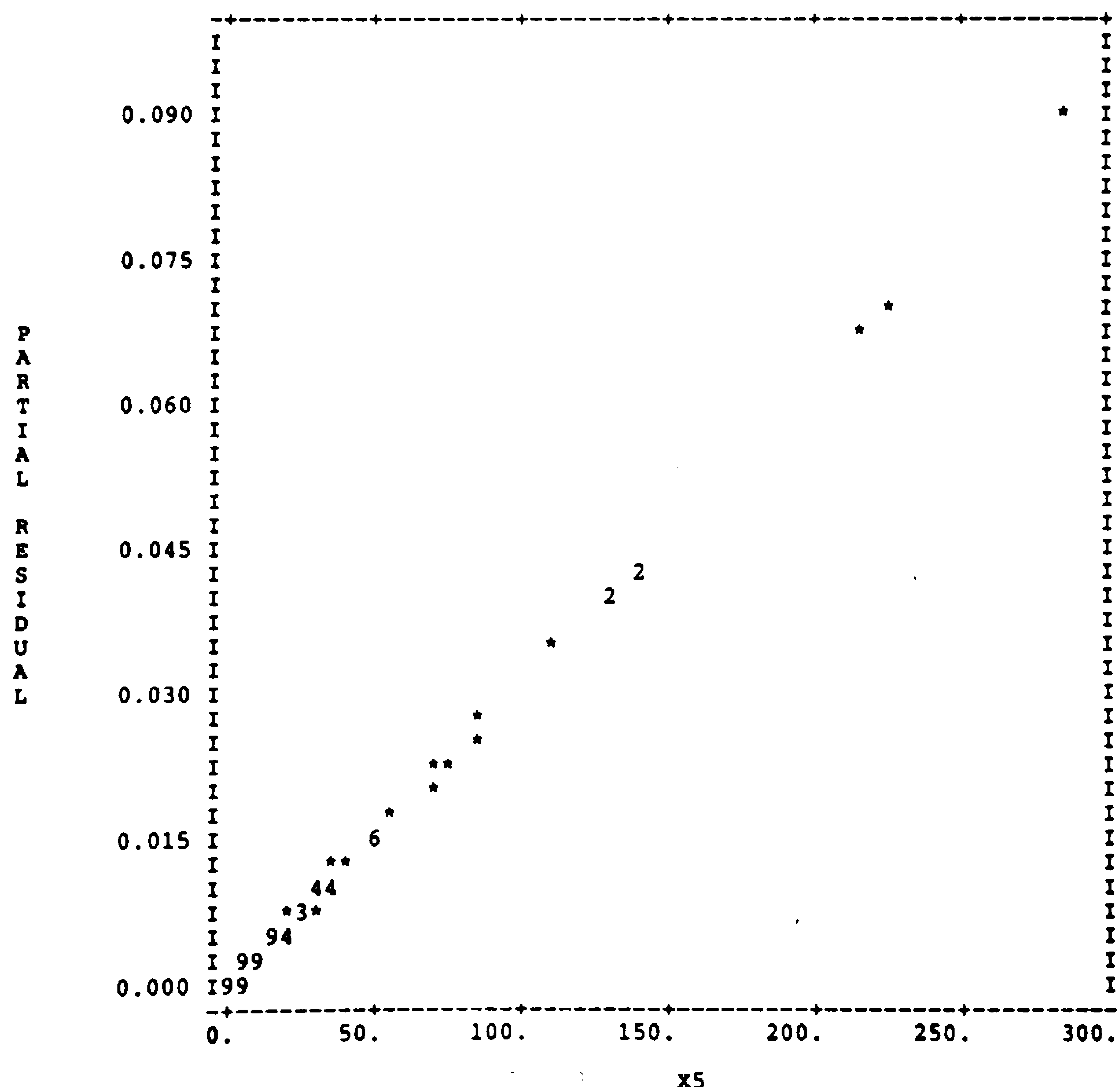


FIGURE 9.5(C)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

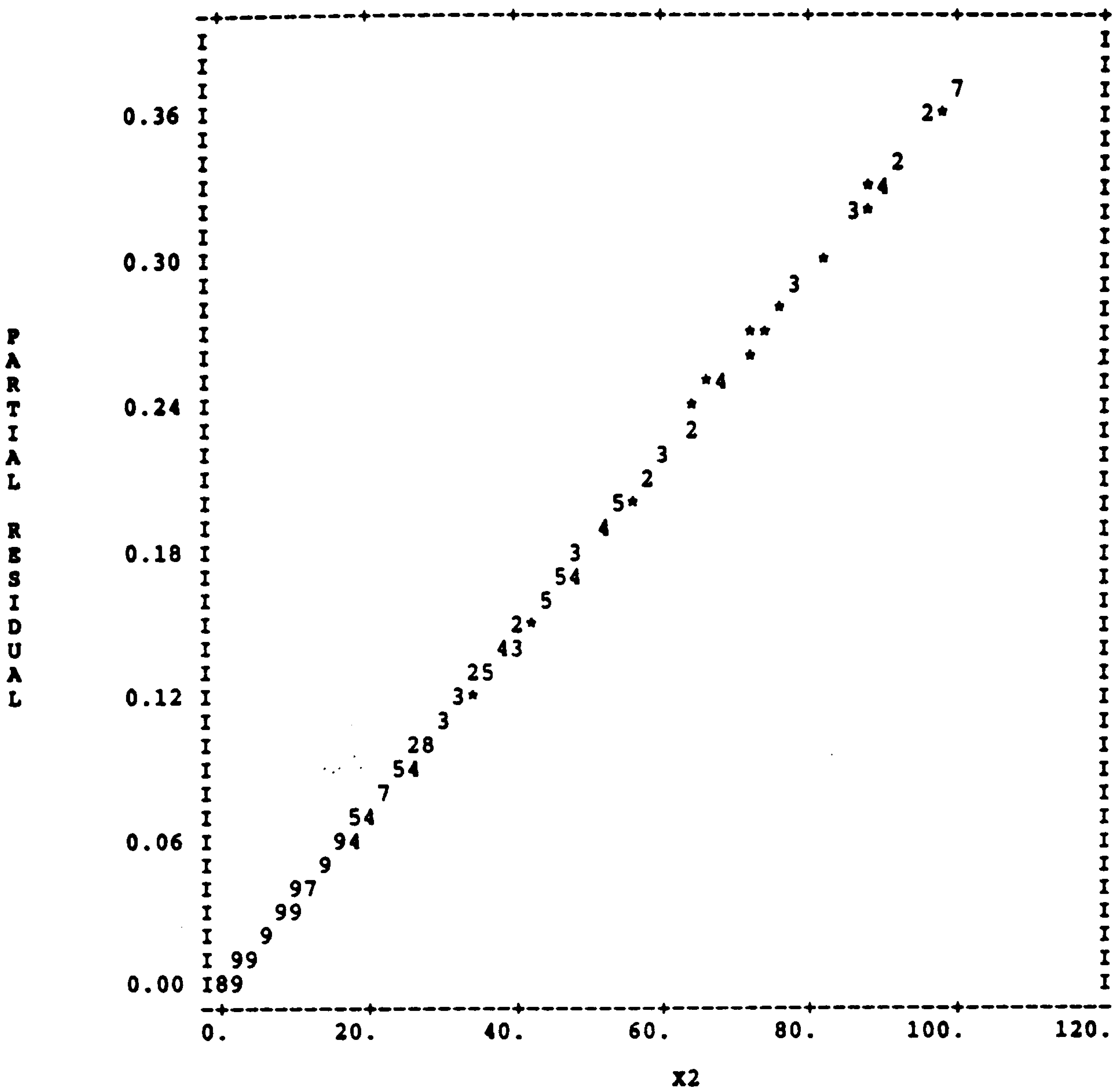


FIGURE 9.5(D)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

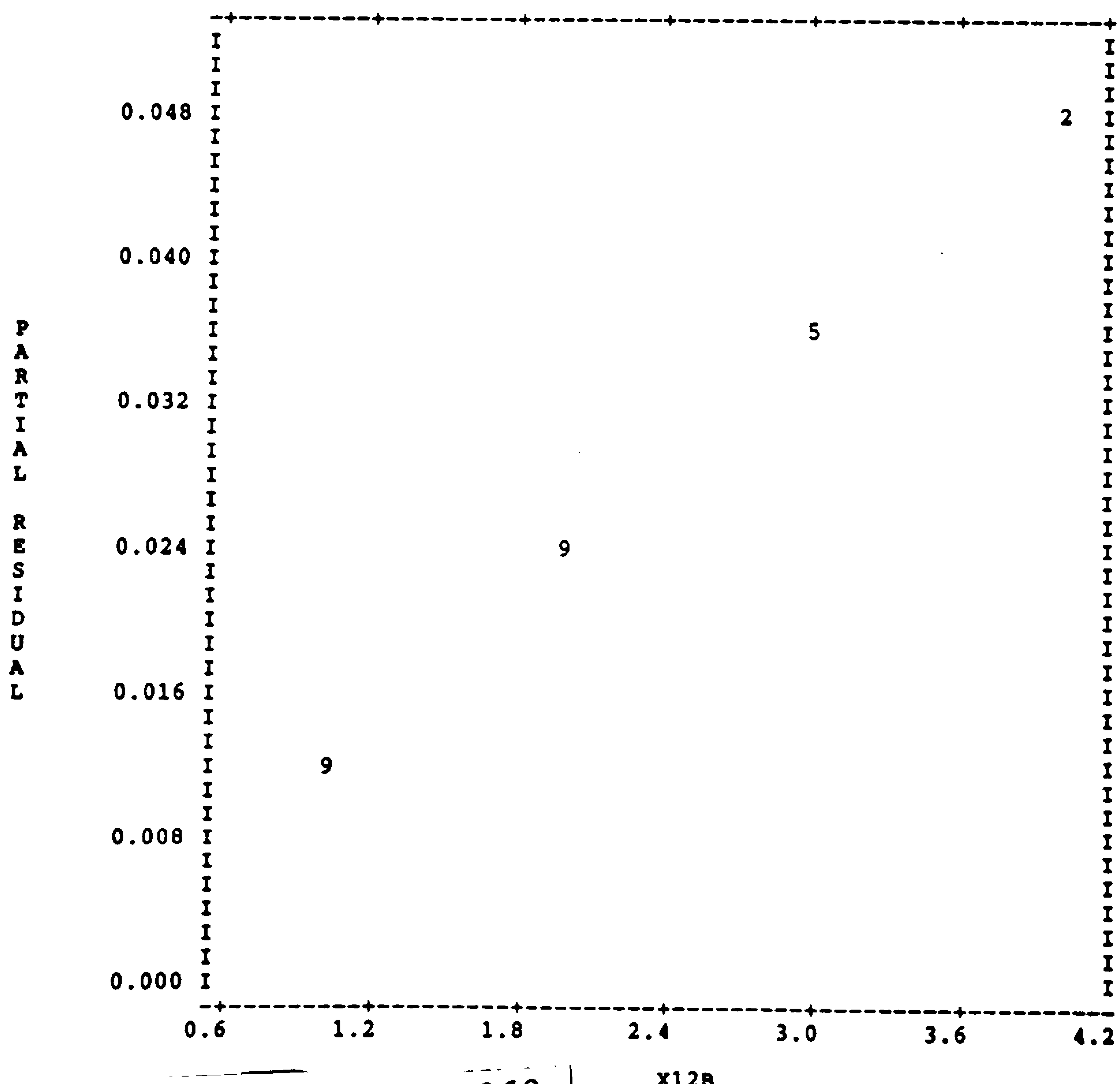


FIGURE 9.5(E)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

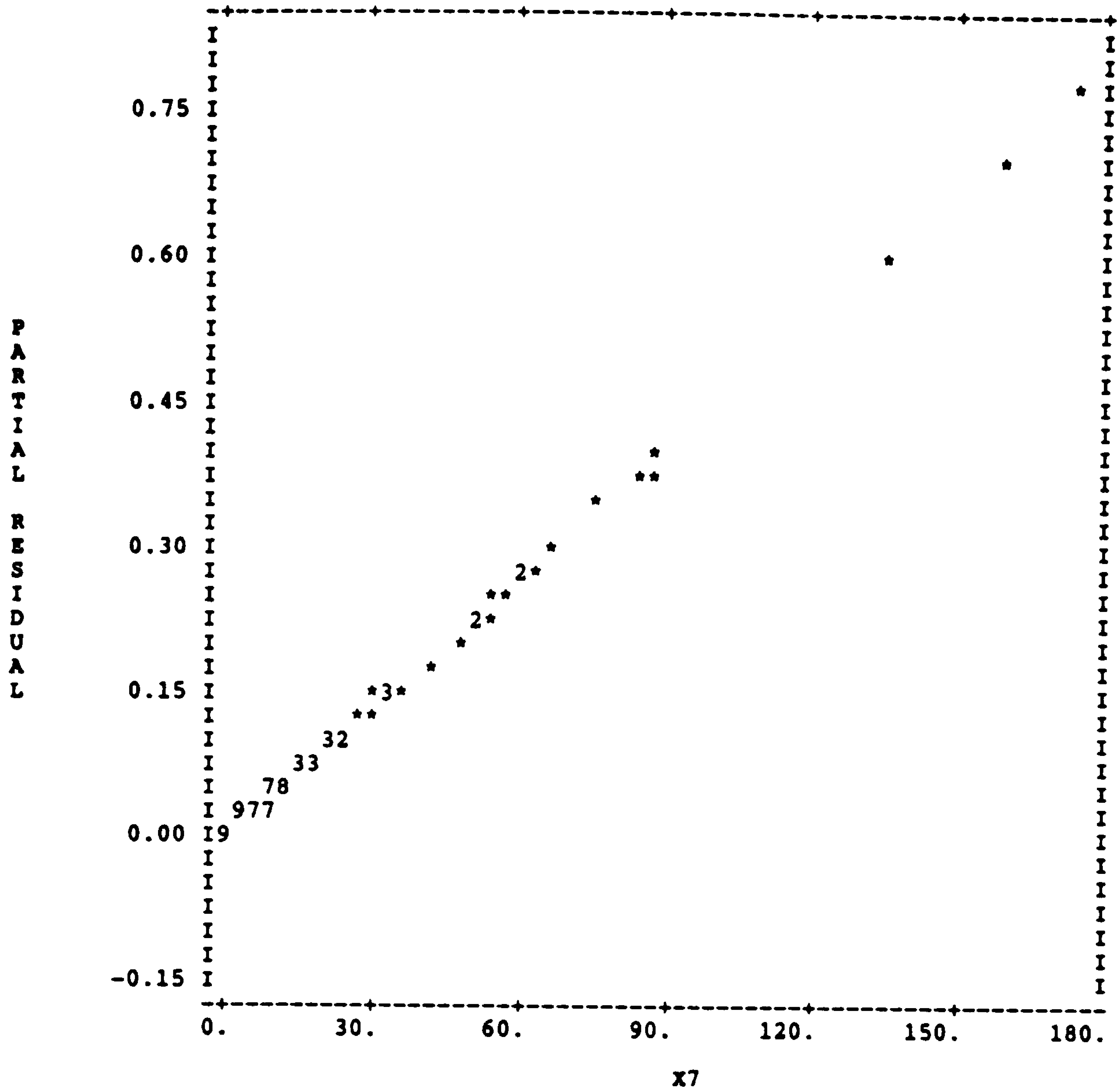


FIGURE 9.5(F)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

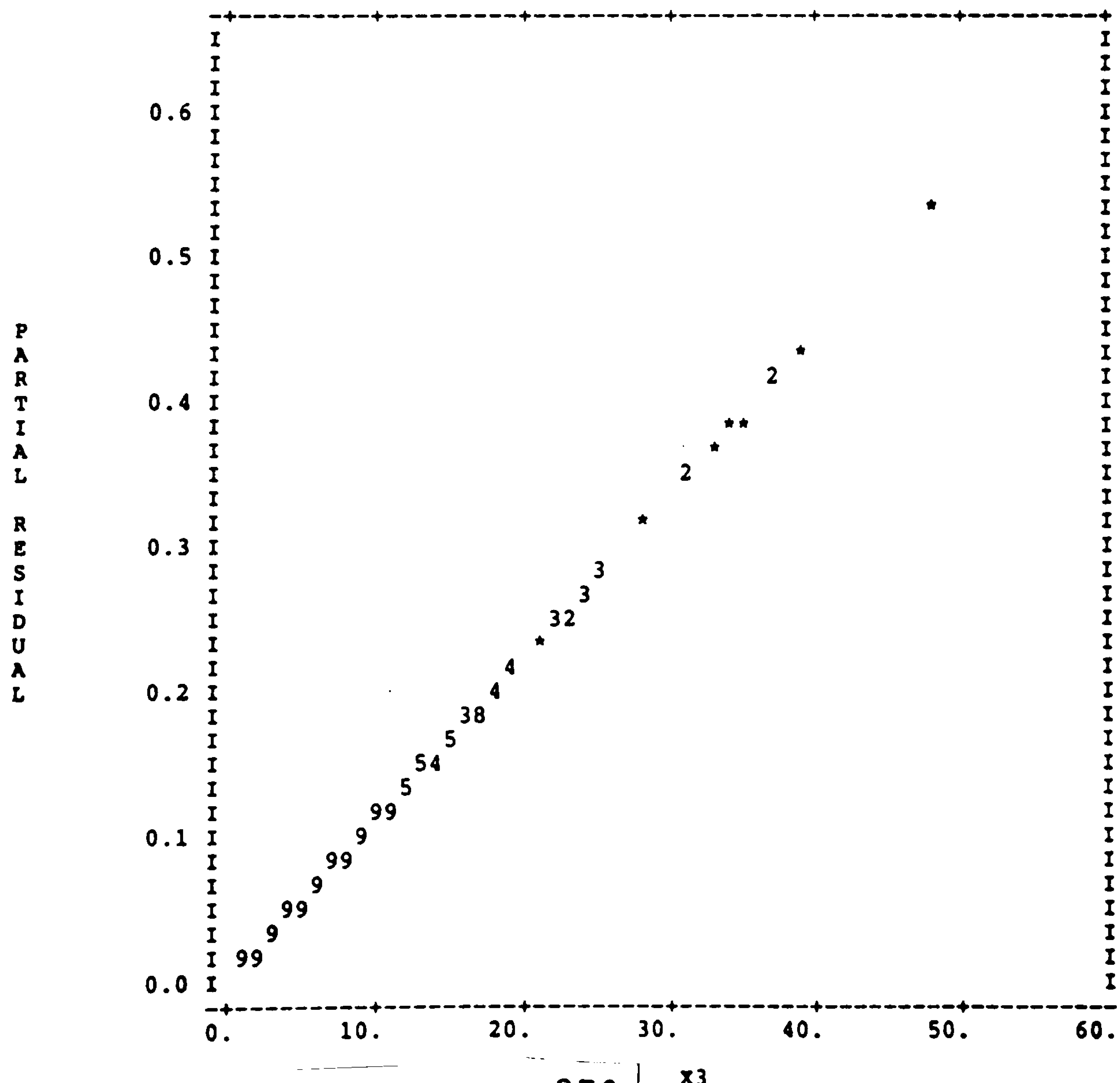


FIGURE 9.5(G)
CHECKING VARIATE SCALE
THEORETICAL MODEL D

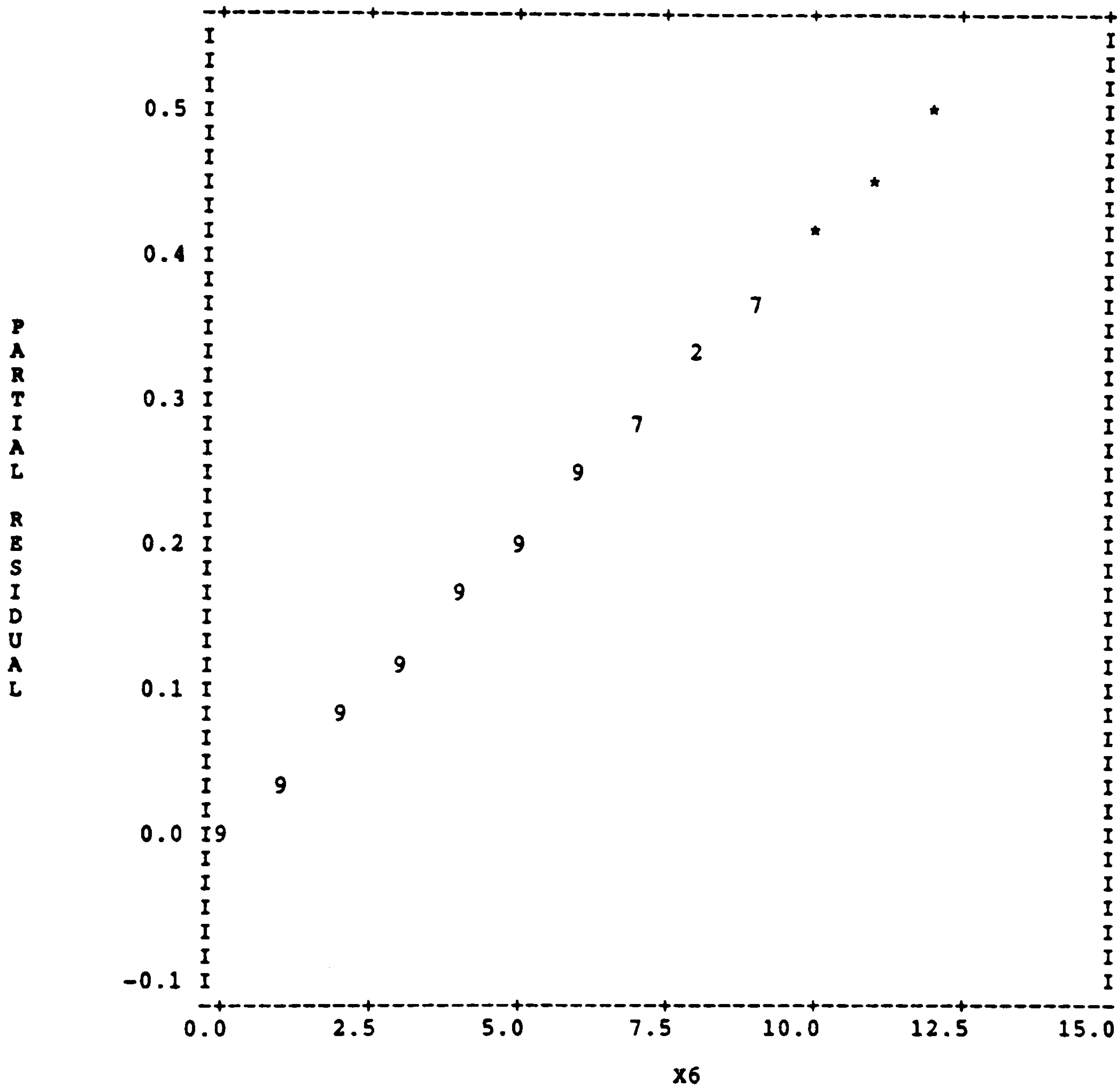


FIGURE 9.6(A)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

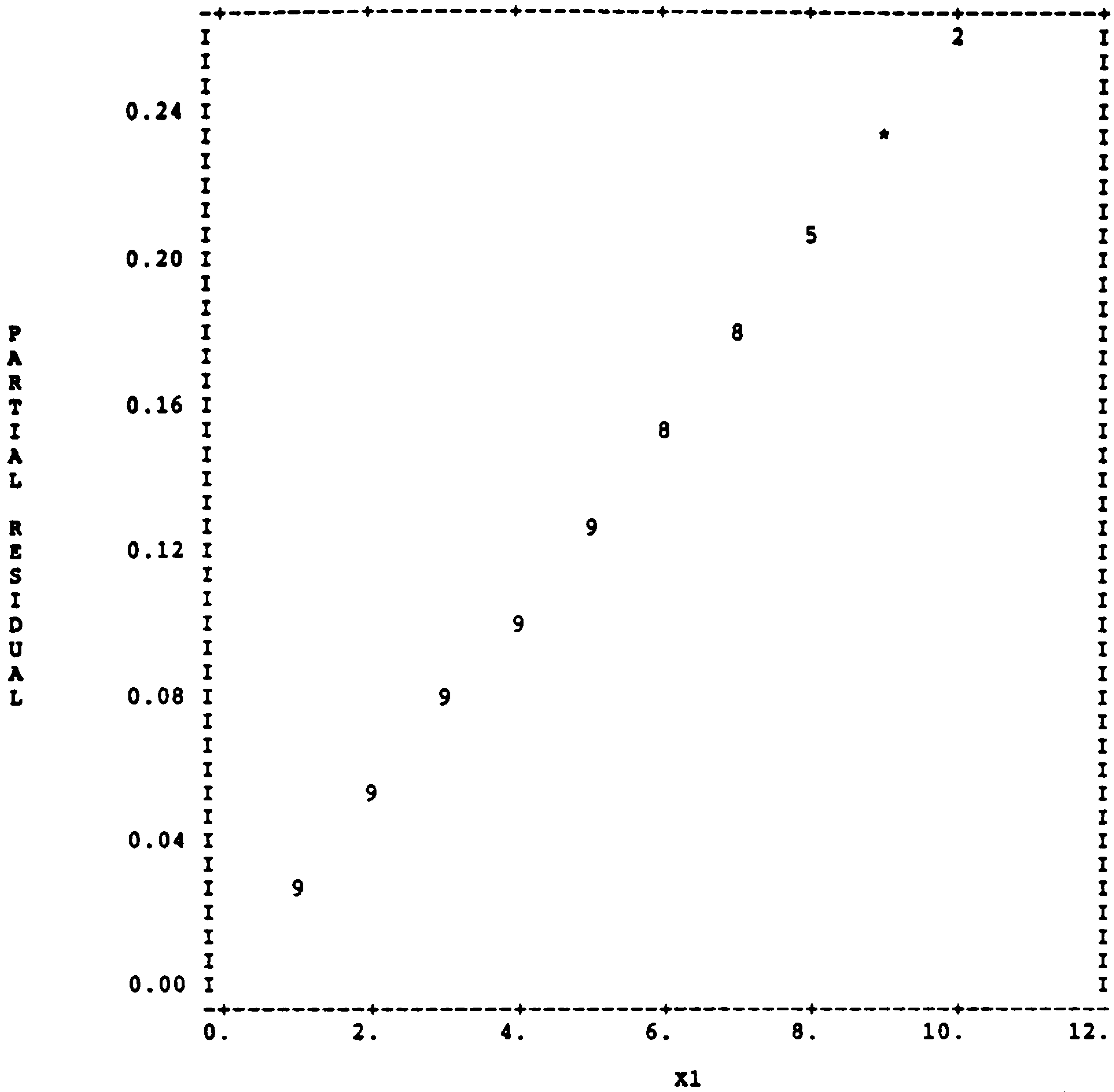


FIGURE 9.6(B)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

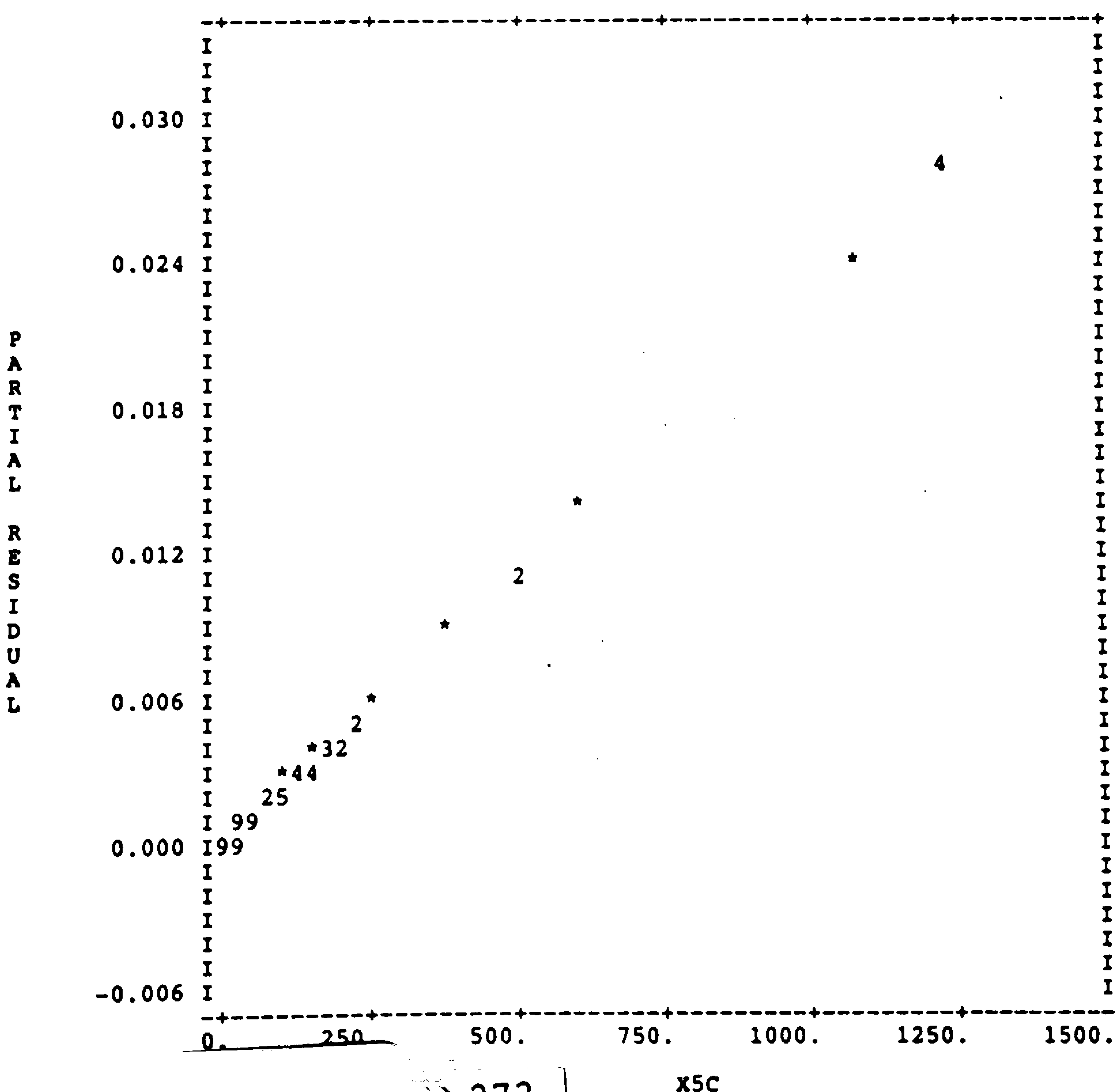


FIGURE 9.6(C)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

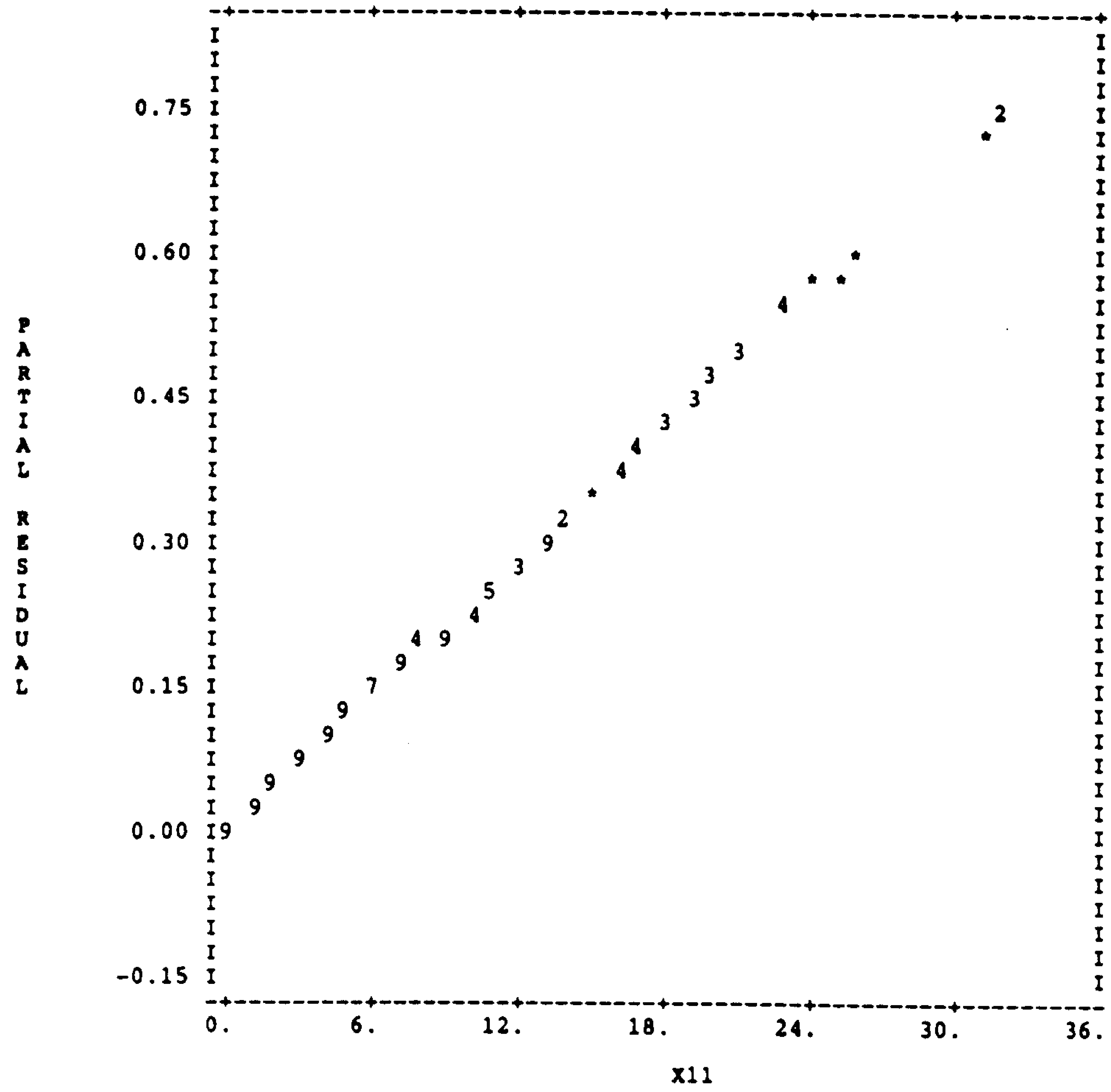


FIGURE 9.6(D)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

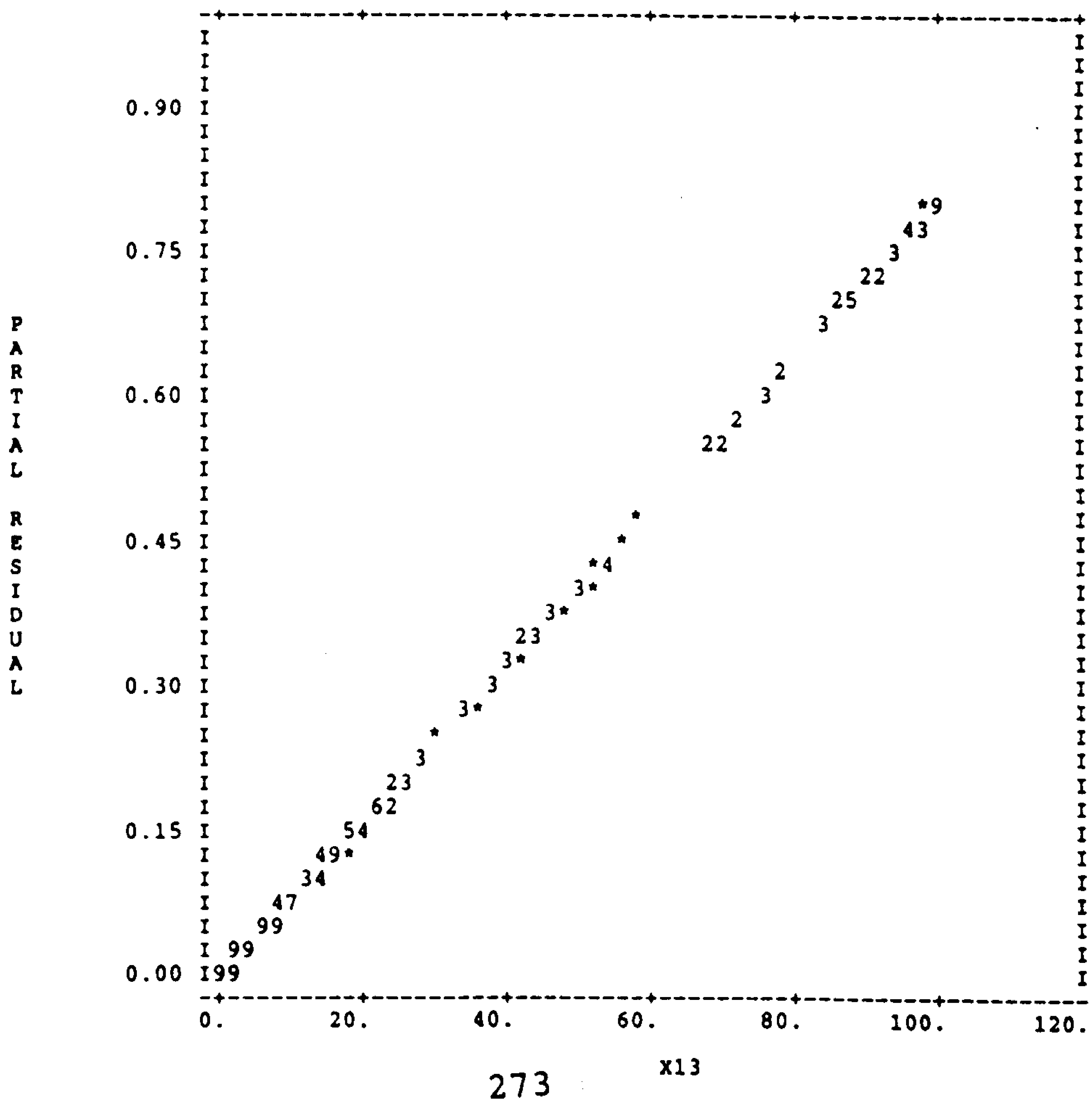


FIGURE 9.6(E)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

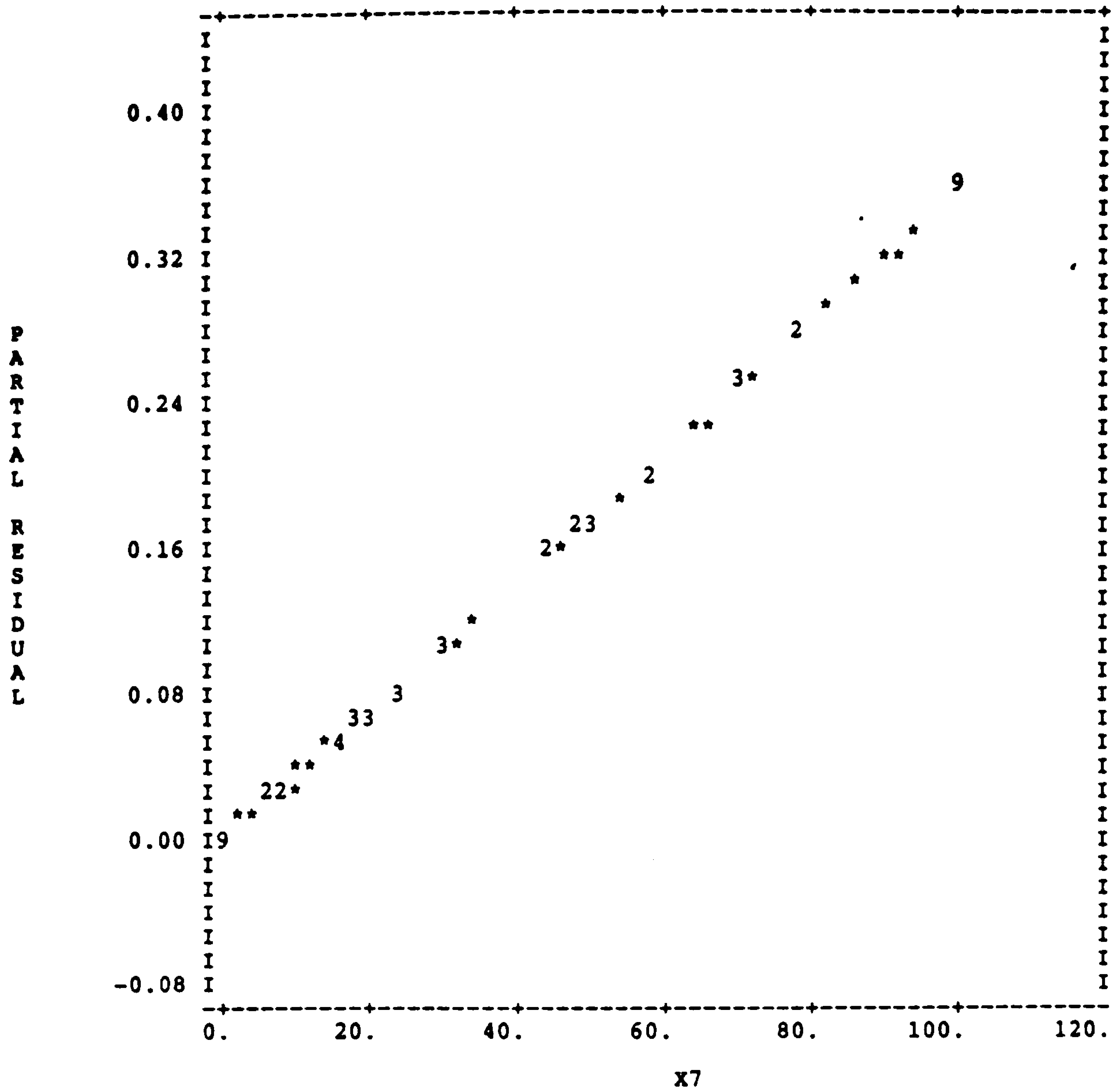


FIGURE 9.6(F)
CHECKING VARIATE SCALE
THEORETICAL MODEL E

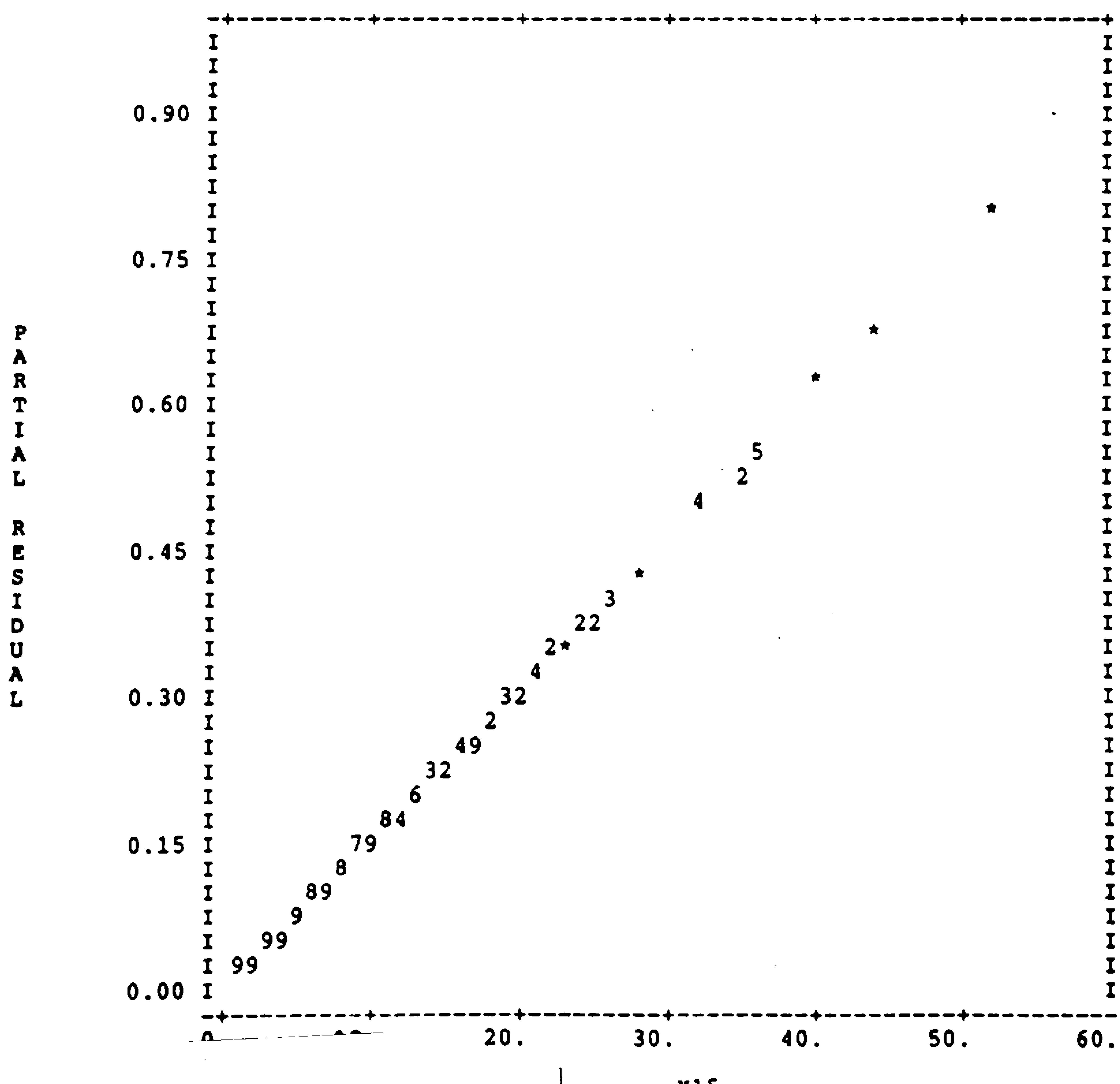
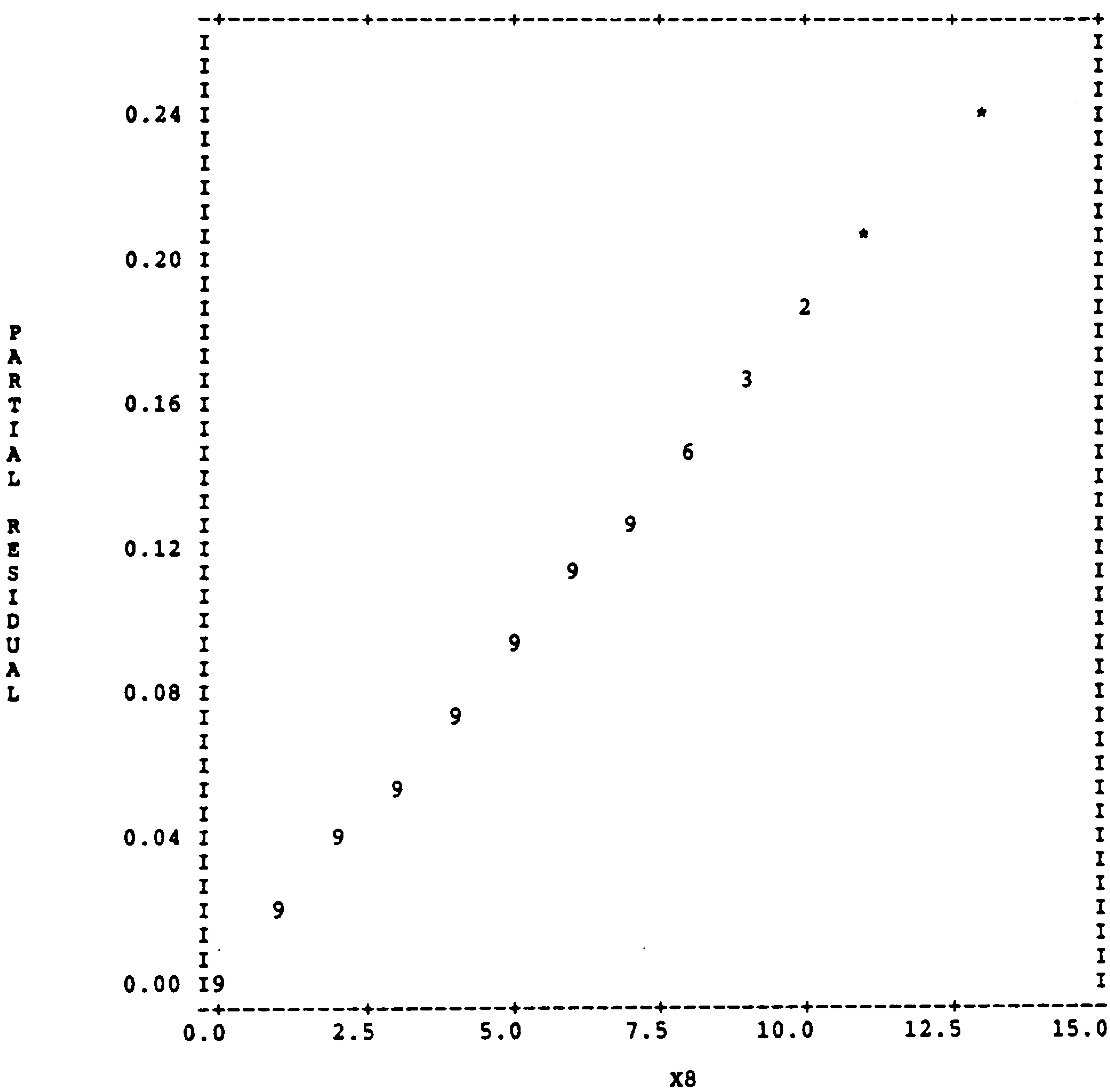


FIGURE 9.6(G)
CHECKING VARIATE SCALE
THEORETICAL MODEL E



detected from the plot which should show non-linearity. Figures 9.7 (a)-(e) show that all models have satisfactory link function.

9.4.5 CHECKING THE VARIANCE FUNCTION -

Homoscedasticity is a condition in which all disturbances have a constant variance. Deviation from disturbances are heteroscedastic. These disturbances may not be significant in GLM because the statistical methodology can overcome both the problem of homoscedasticity and heteroscedasticity. Several different statistical tests are available for deciding whether error terms in the model have unequal variances. Examination of the plot of residuals and predicted responses was suggested and described at length by Gunst and Mason (331).

Plots of Residuals (not standardized) against Fitted Value will indicate that the spread of residuals is approximately constant and independent of fitted values. If this plot shows signs of rapid decrease with increasing fitted values then the variance function is actually increasing in the opposite manner. Although with the binomial data in this research, it may be difficult to interpret as many 'y' values clustered in the region of 0 to 100 observations with less observations in the higher order observations of more than 100. The test on all models, as shown in Figures 9.8(a)-(e) show that all models have variance function of left opening-megaphone and that the variance function is decreasing as the fitted values

FIGURE 9.7(A)
CHECKING LINK FUNCTION
THEORETICAL MODEL A

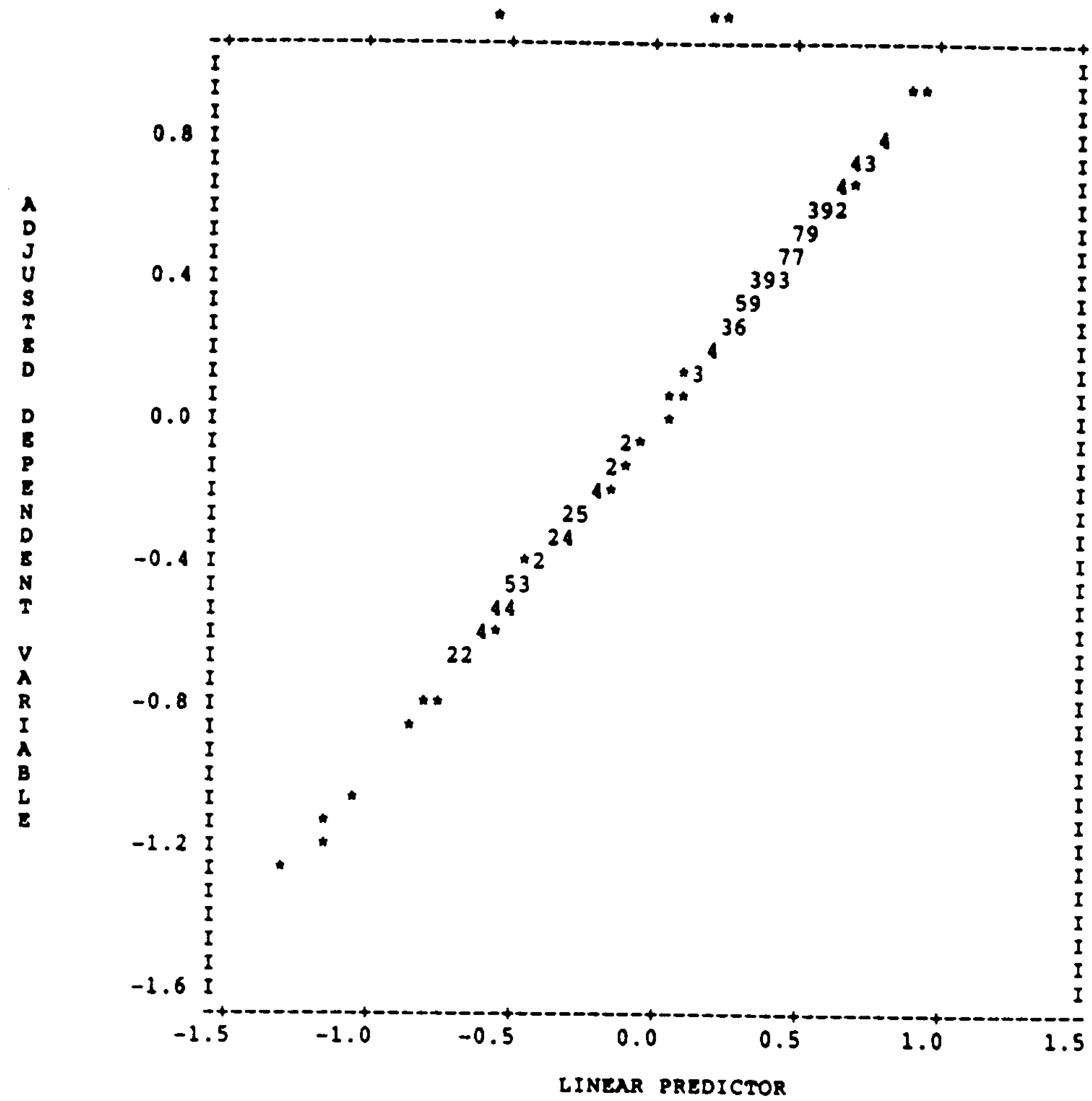


FIGURE 9.7(B)
CHECKING LINK FUNCTION
THEORETICAL MODEL B

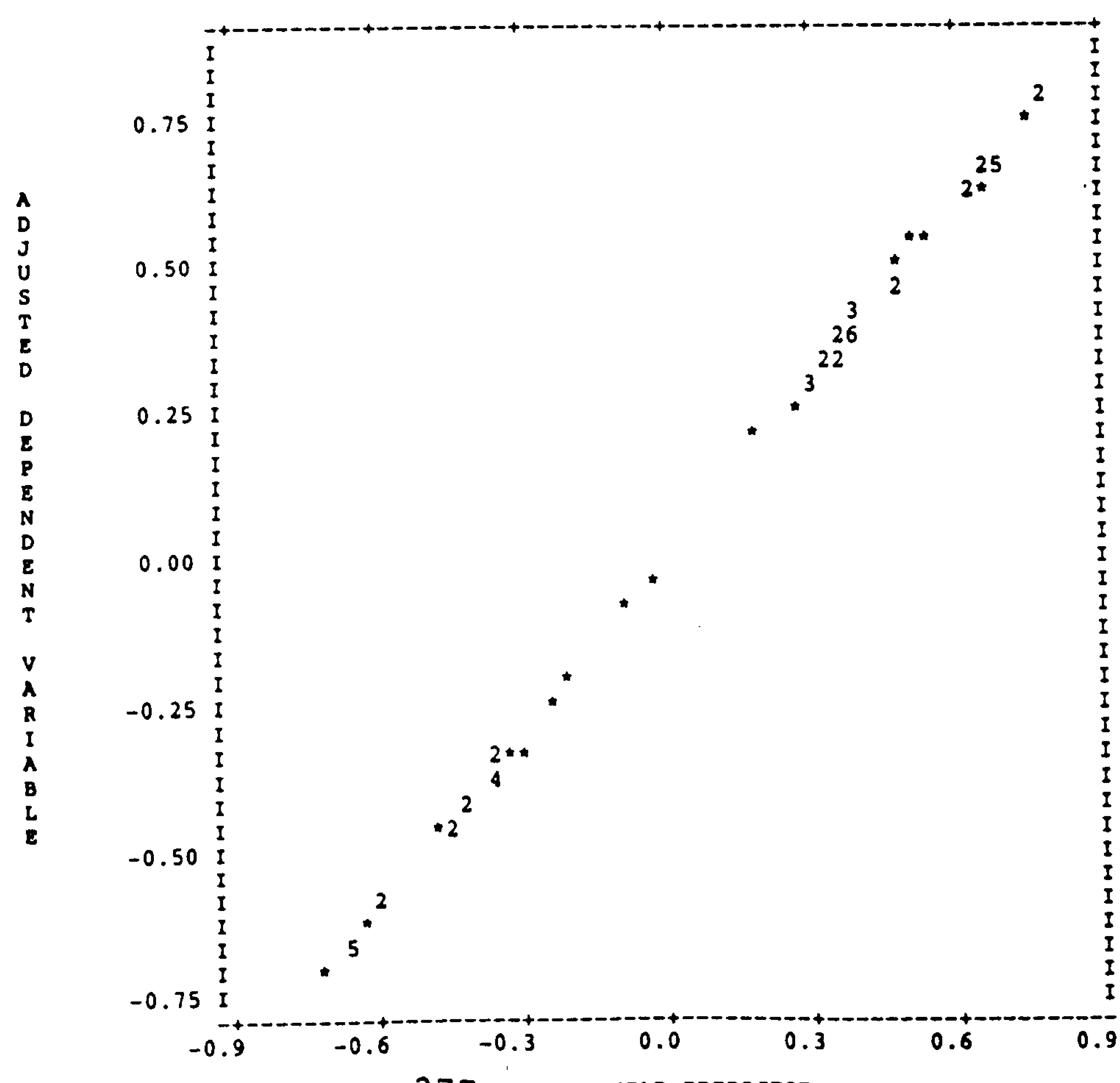


FIGURE 9.7(C)
CHECKING LINK FUNCTION
THEORETICAL MODEL C

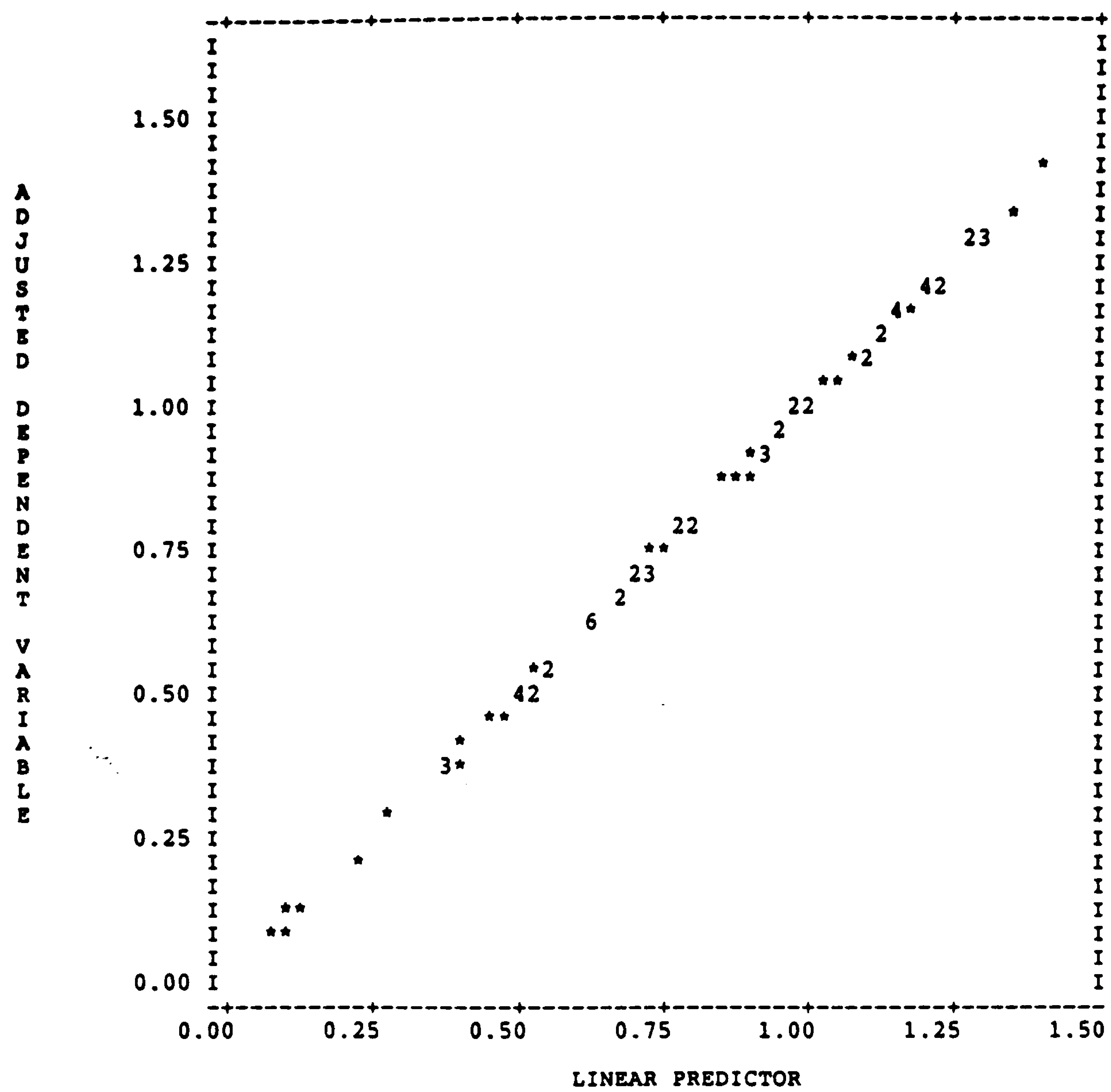


FIGURE 9.7(D)
CHECKING LINK FUNCTION
THEORETICAL MODEL D

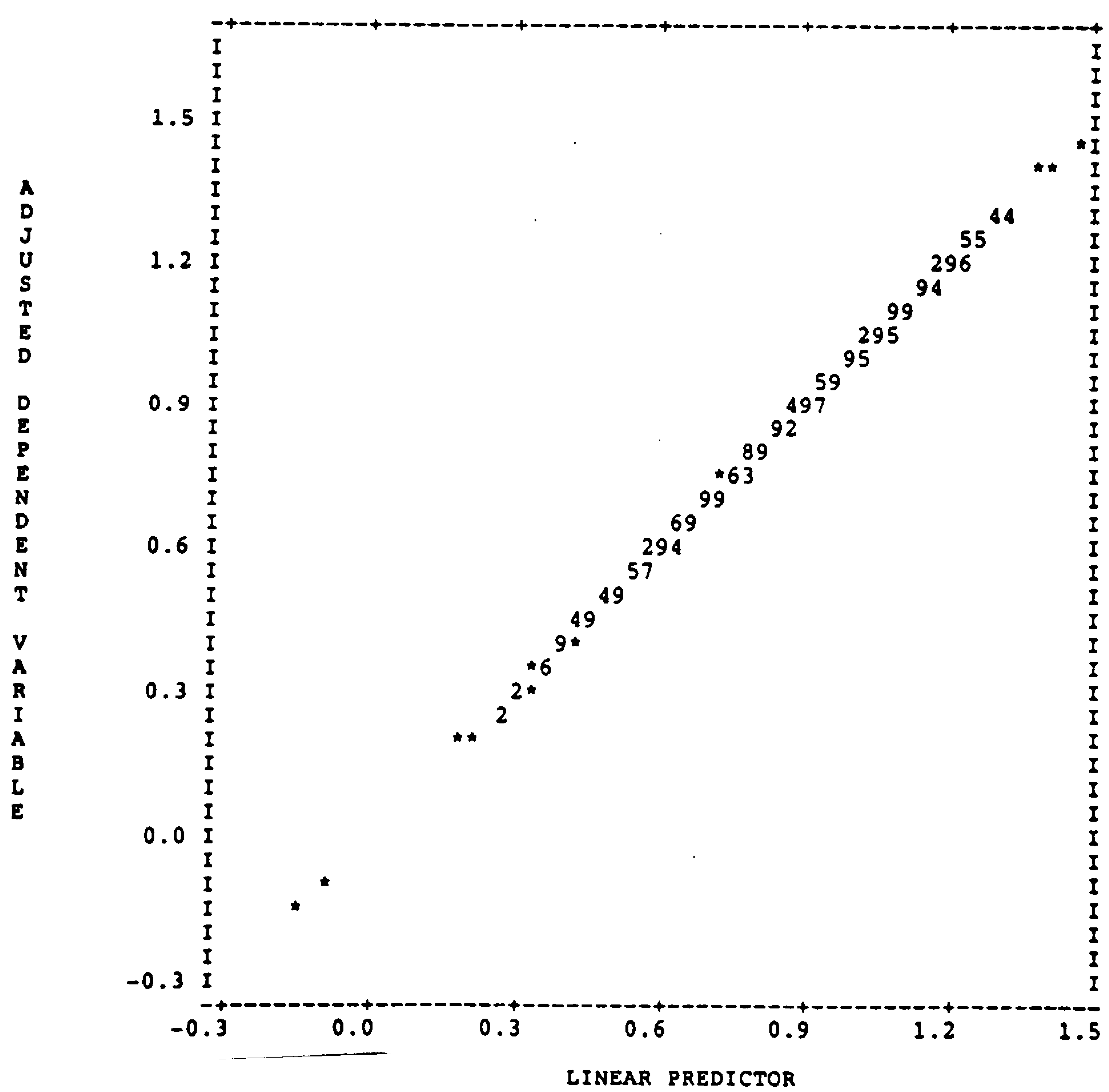


FIGURE 9.7(E)
CHECKING LINK FUNCTION
THEORETICAL MODEL E

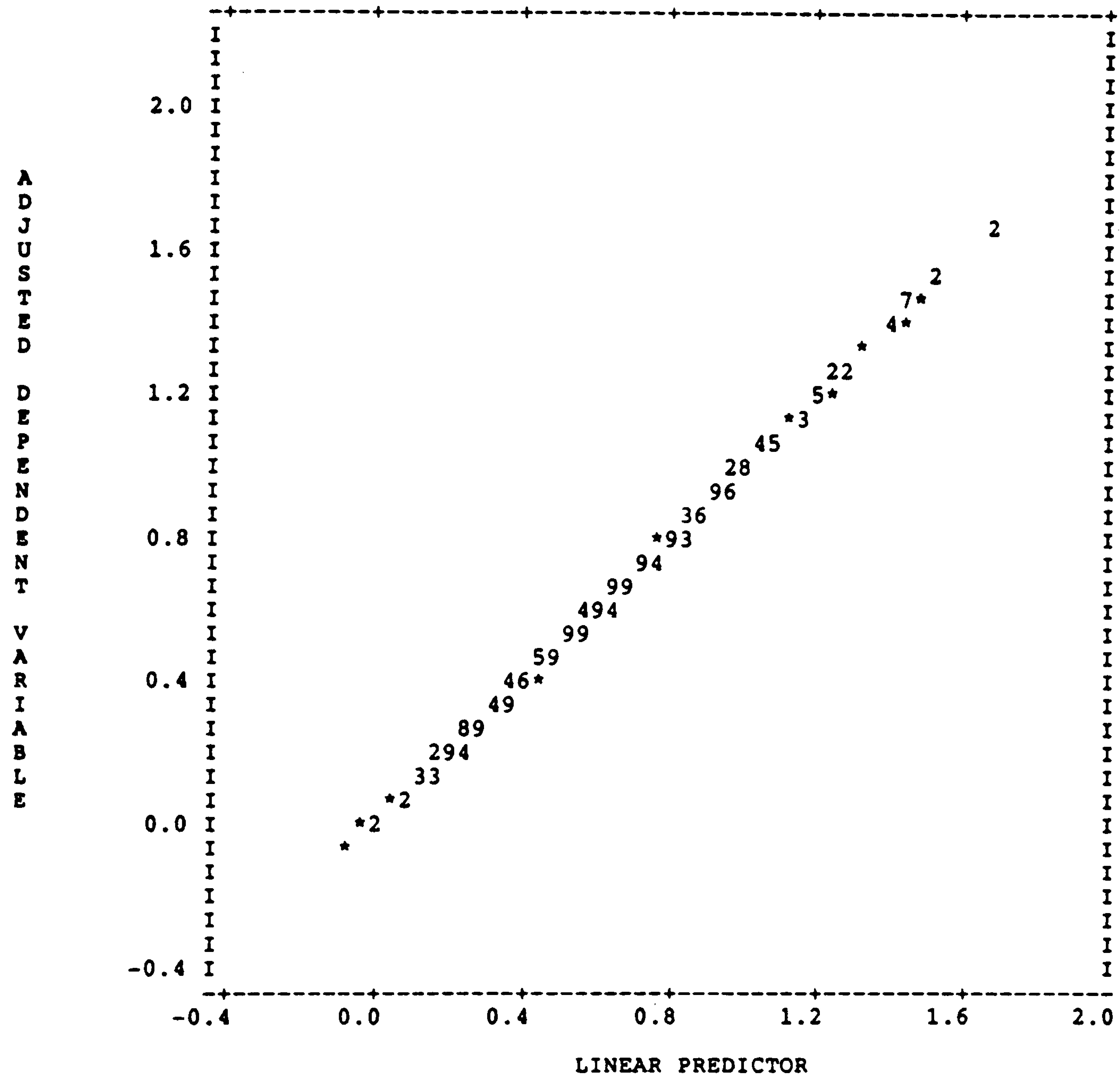


FIGURE 9.8(A)
CHECKING VARIANCE FUNCTION
THEORETICAL MODEL A

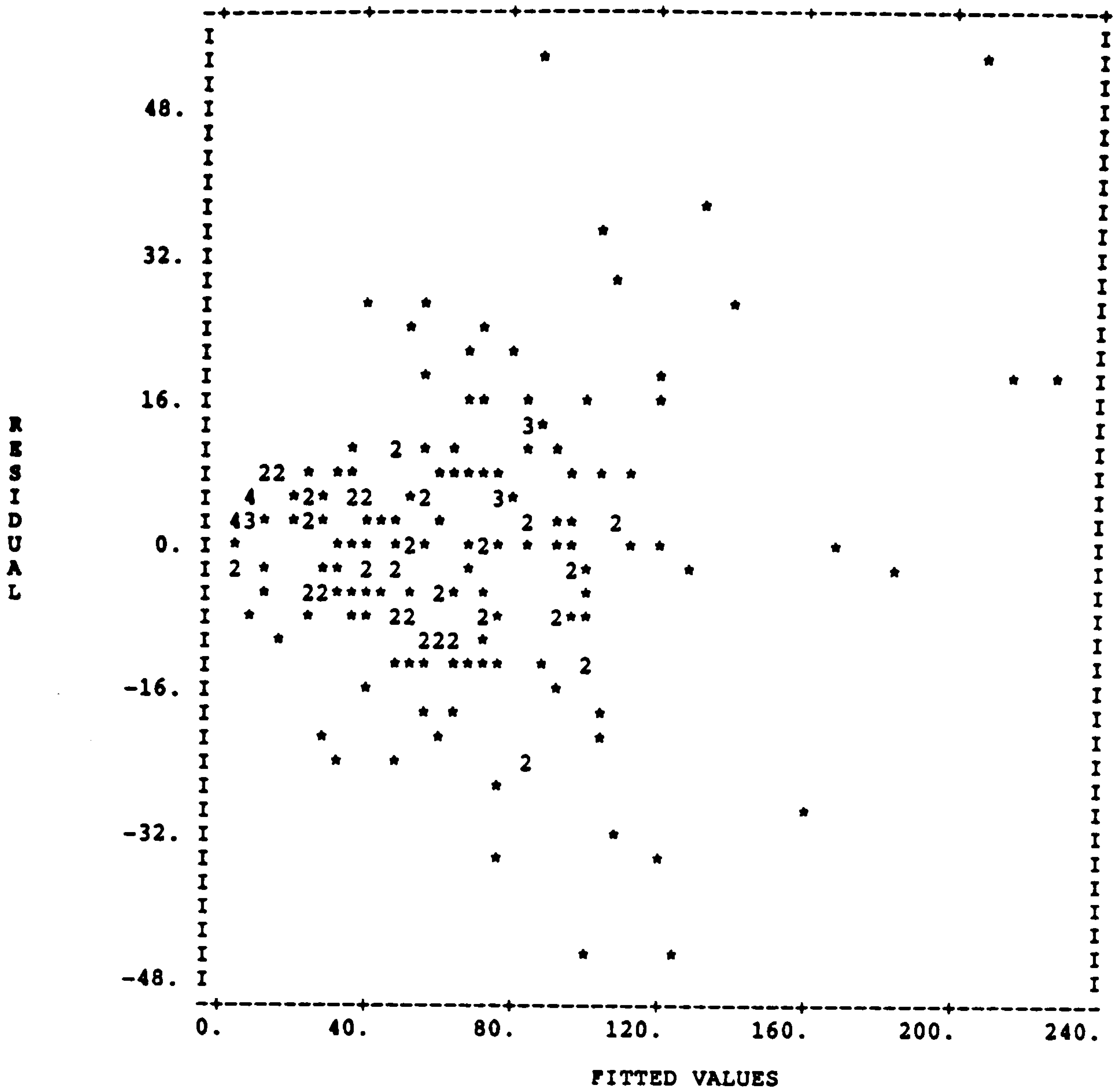


FIGURE 9.8(B)
CHECKING VARIANCE FUNCTION
THEORETICAL MODEL B

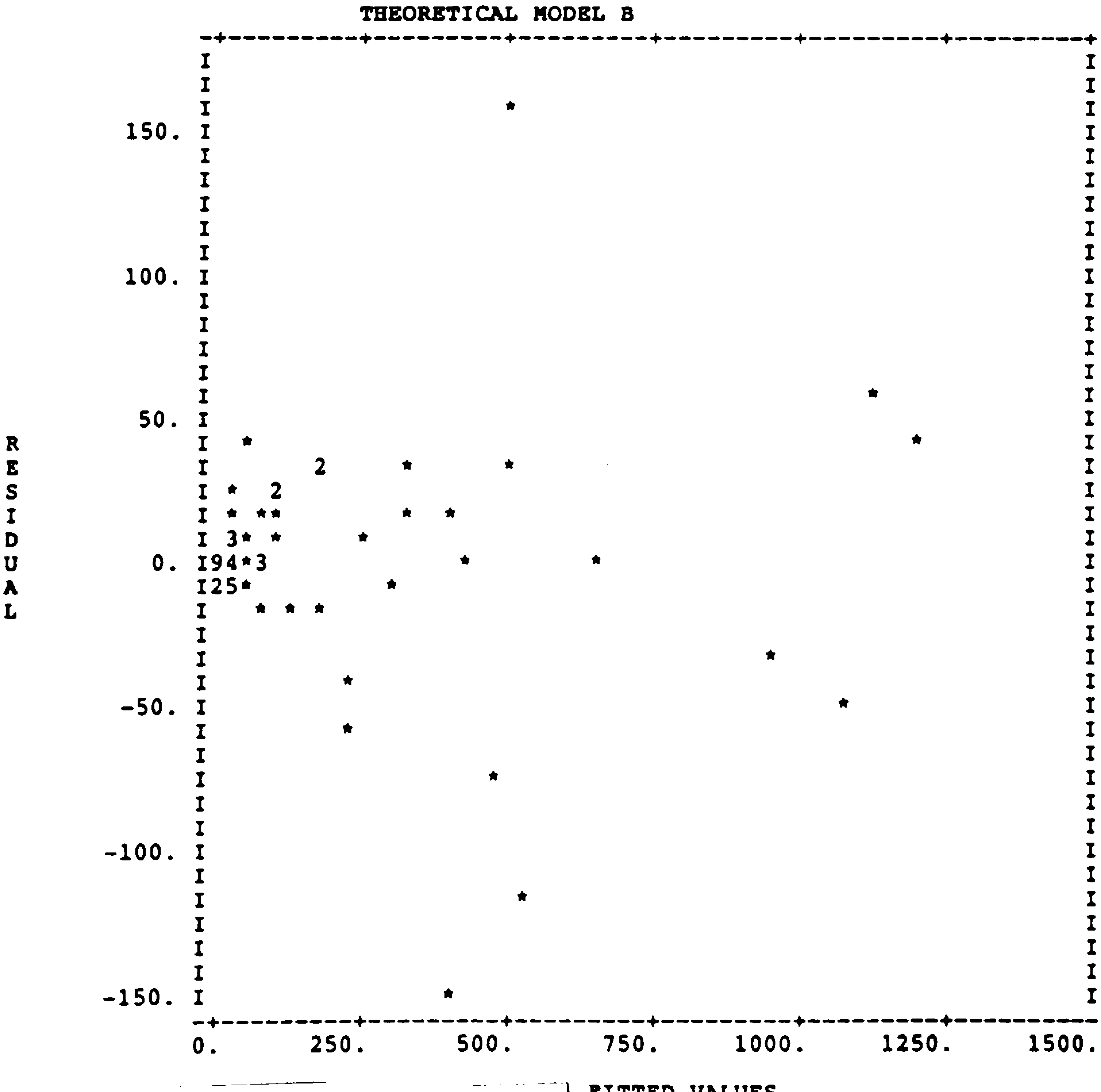


FIGURE 9.8(C)
CHECKING VARIANCE FUNCTION
THEORETICAL MODEL C

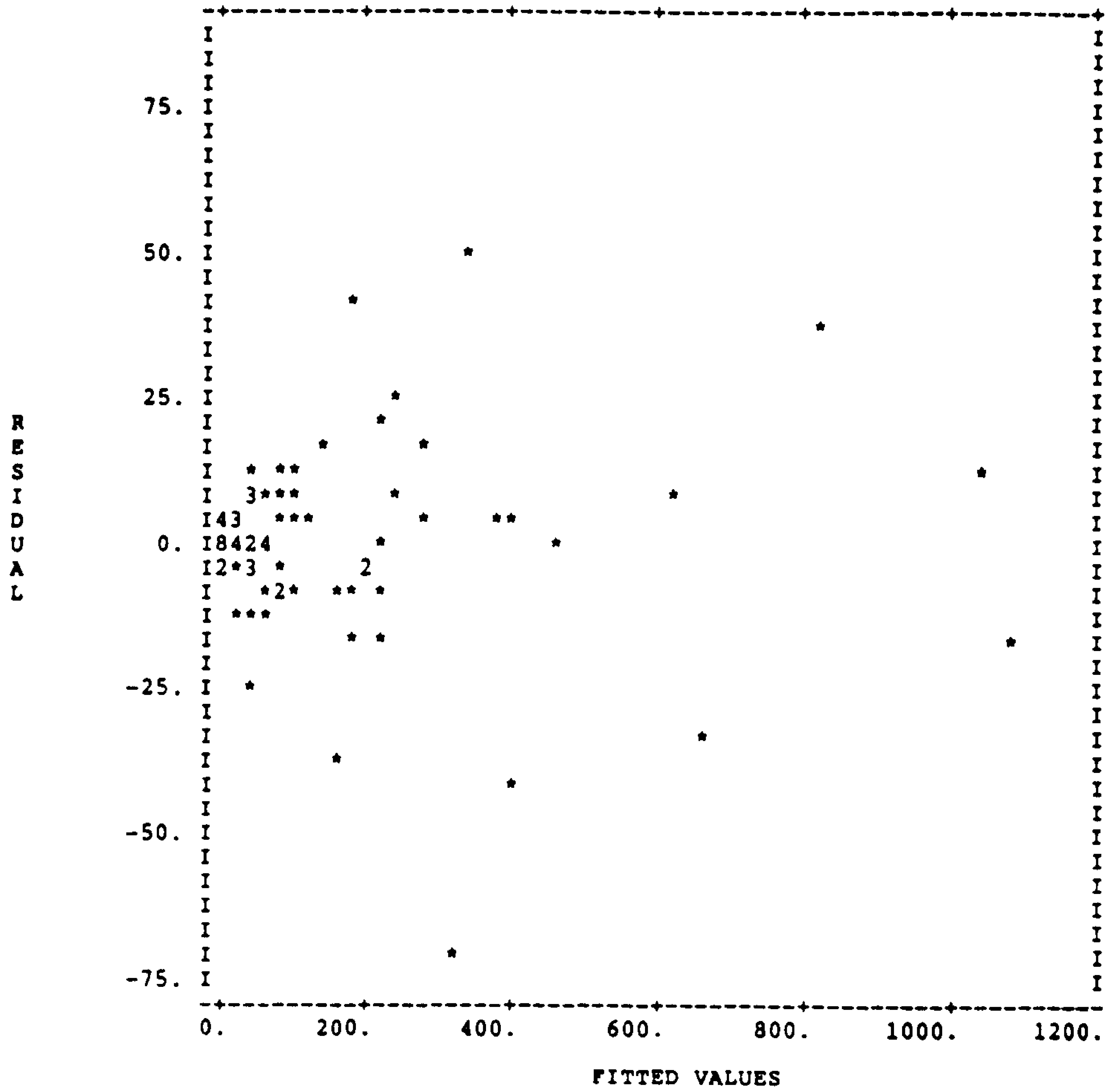
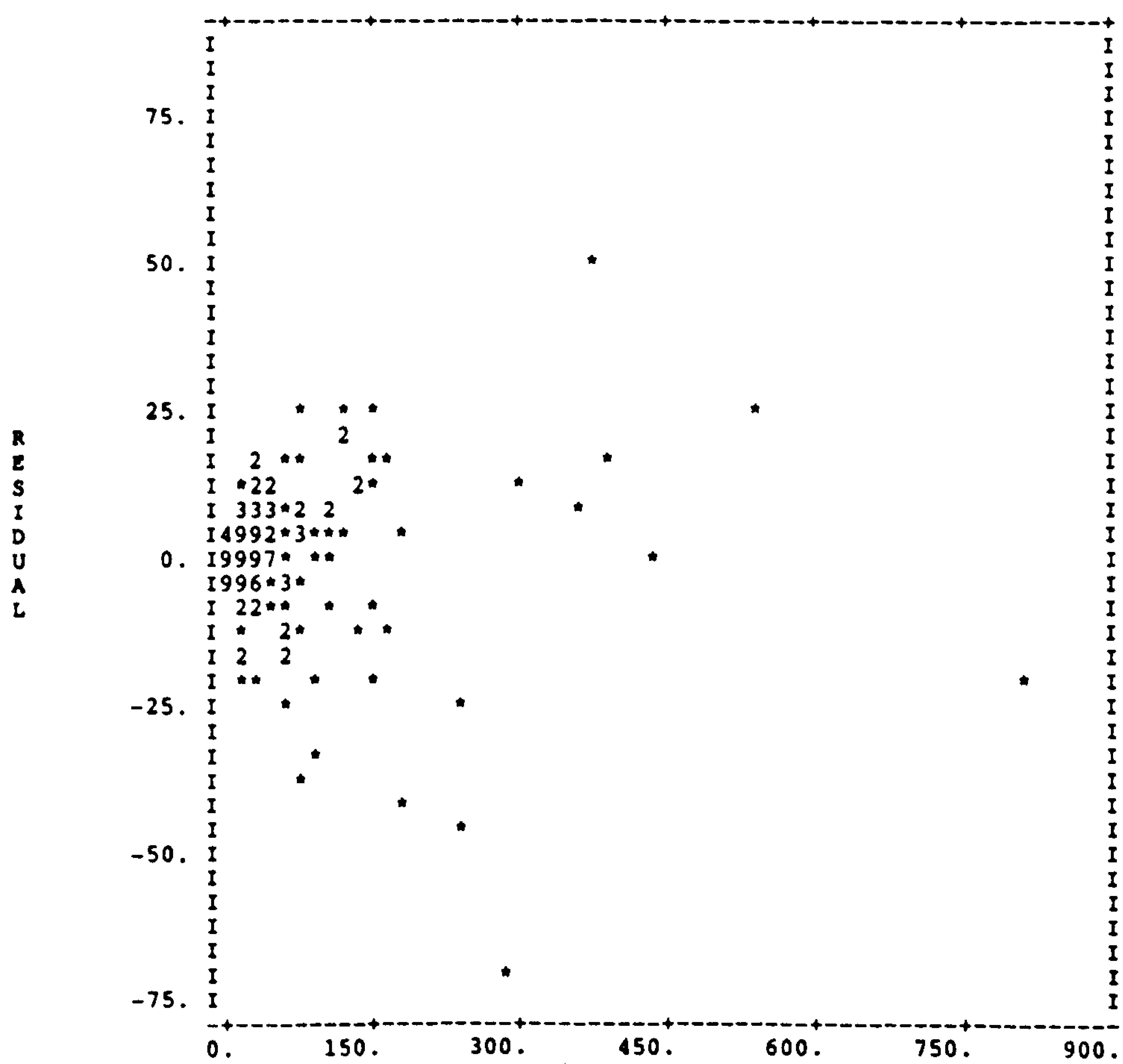


FIGURE 9.8(D)
CHECKING VARIANCE FUNCTION
THEORETICAL MODEL D



FITTED VALUES

FIGURE 9.8(E)
CHECKING VARIANCE FUNCTION
THEORETICAL MODEL E

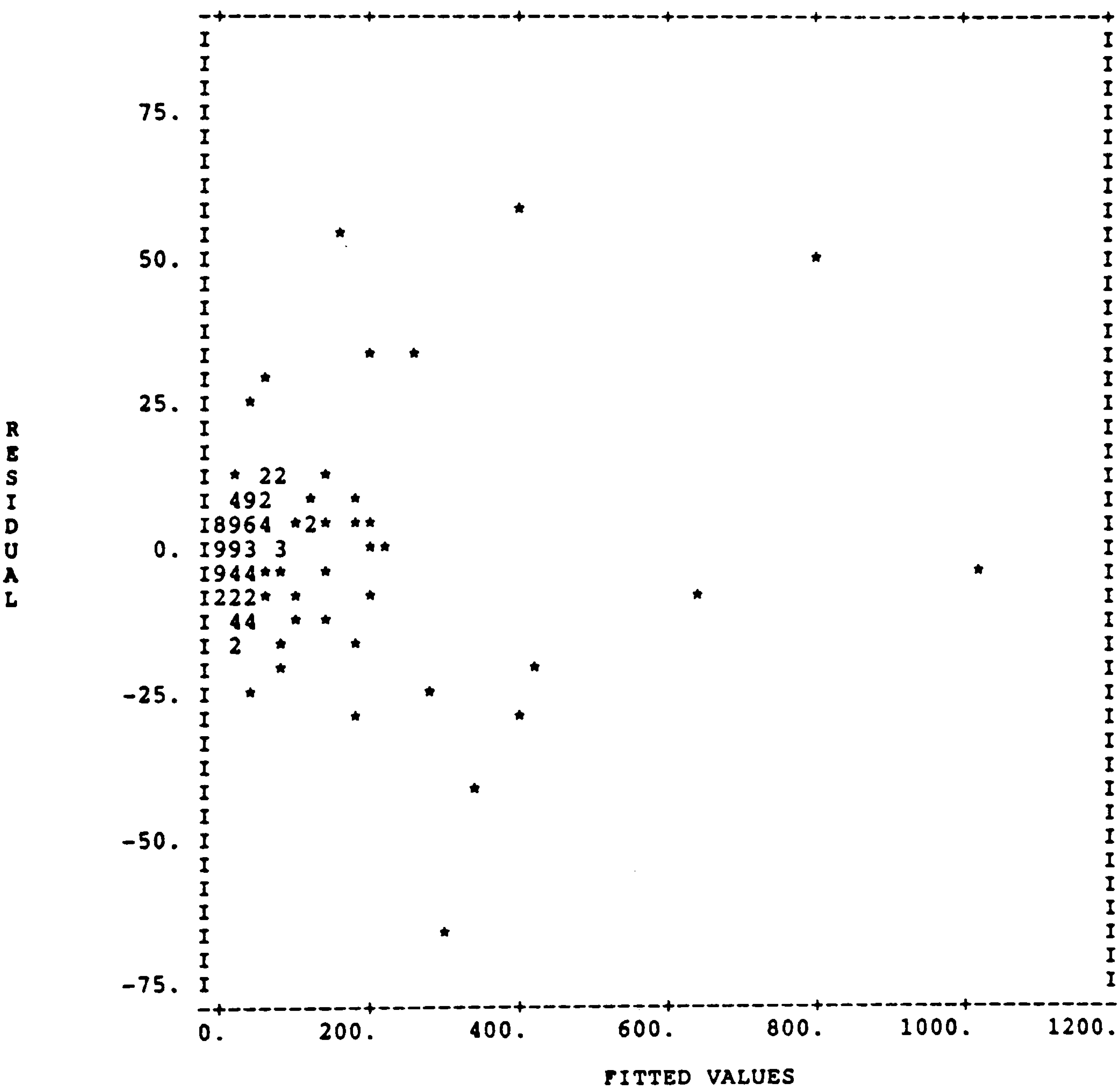


FIGURE 9.9(A)
RESIDUAL PLOT AGAINST TRANSFORMED NP
THEORETICAL MODEL A

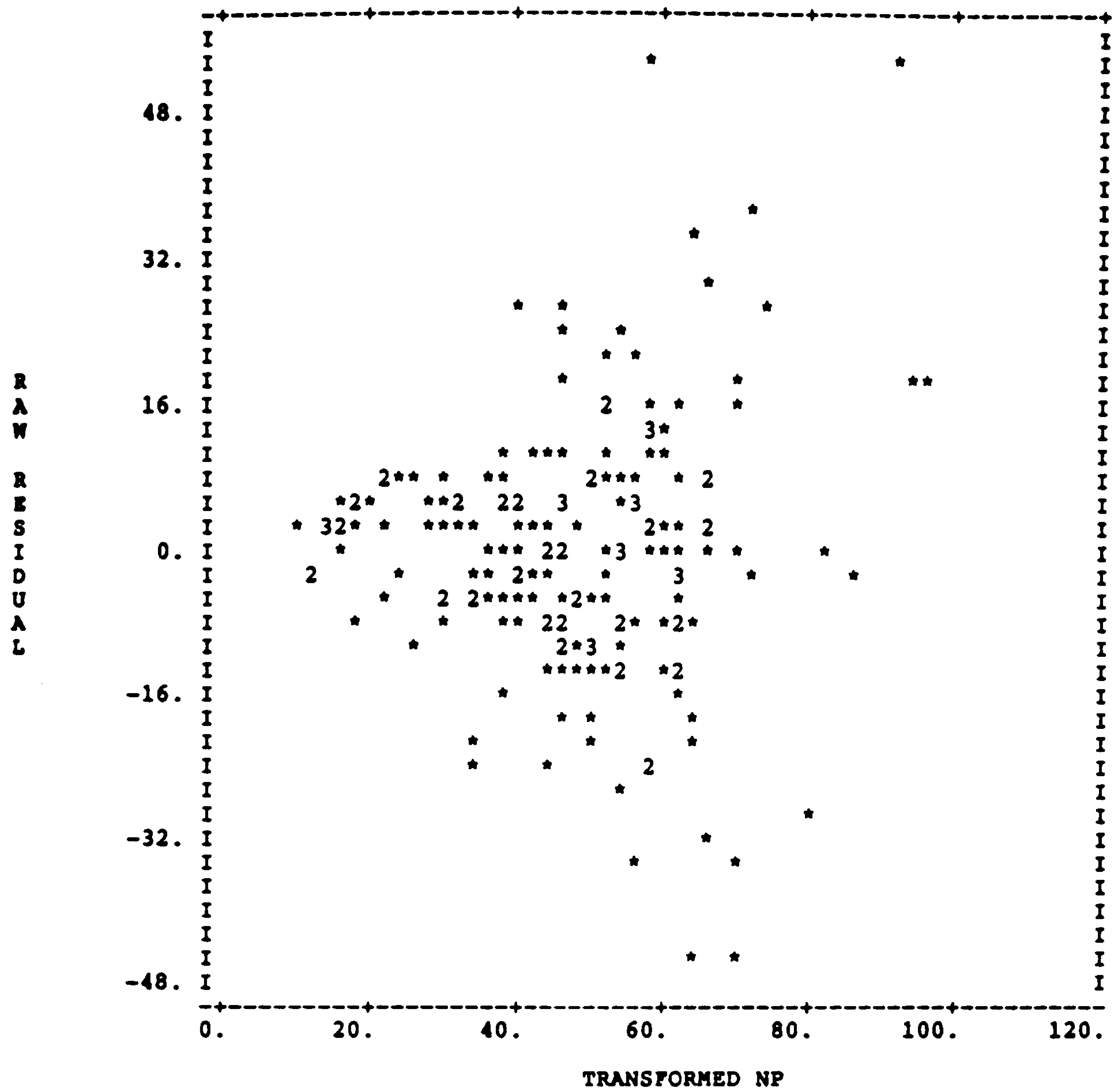


FIGURE 9.9(B)
RESIDUAL PLOT AGAINST TRANSFORMED NP
THEORETICAL MODEL B

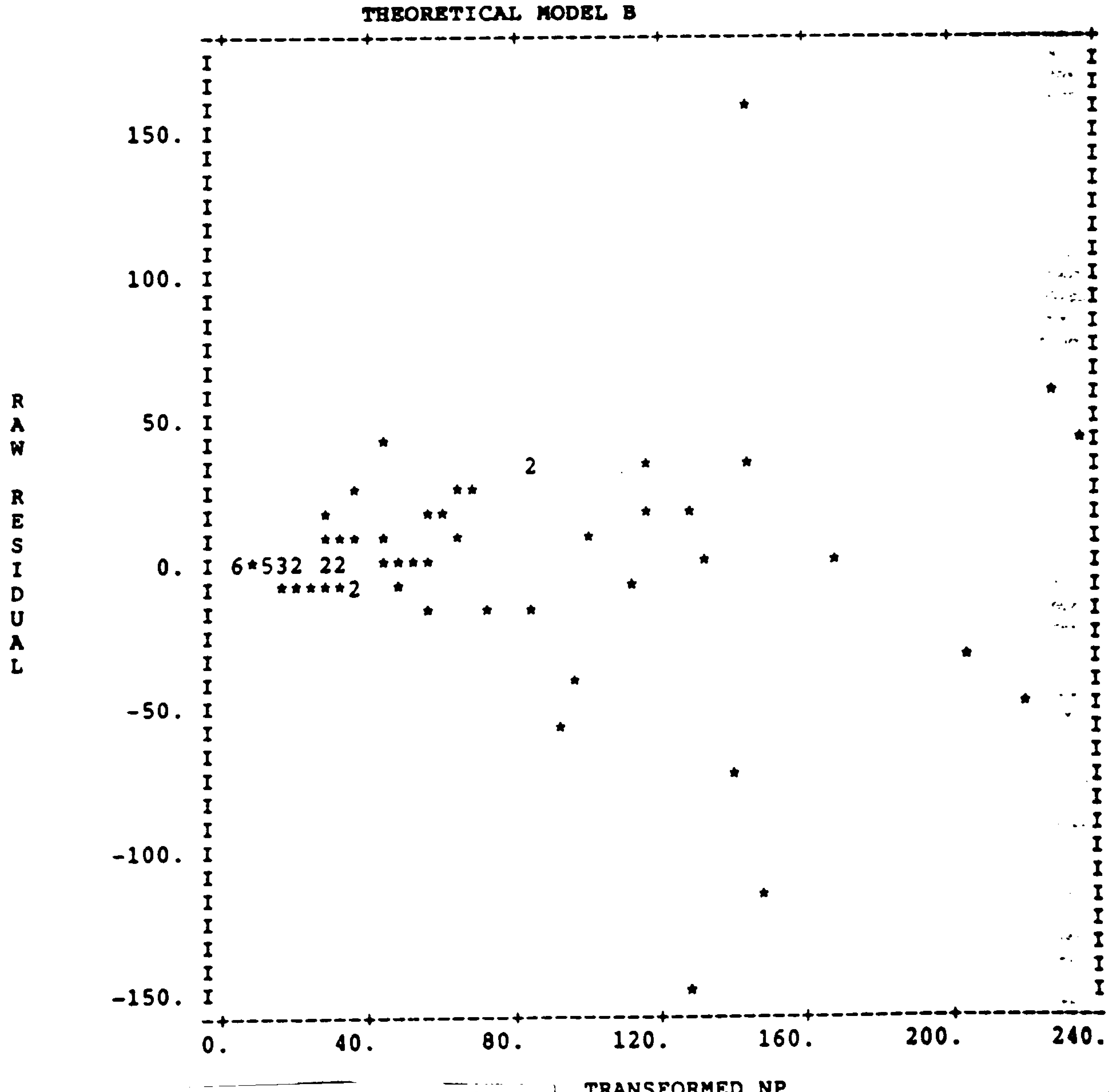


FIGURE 9.9(C)
RESIDUAL PLOT AGAINST TRANSFORMED NP
THEORETICAL MODEL C

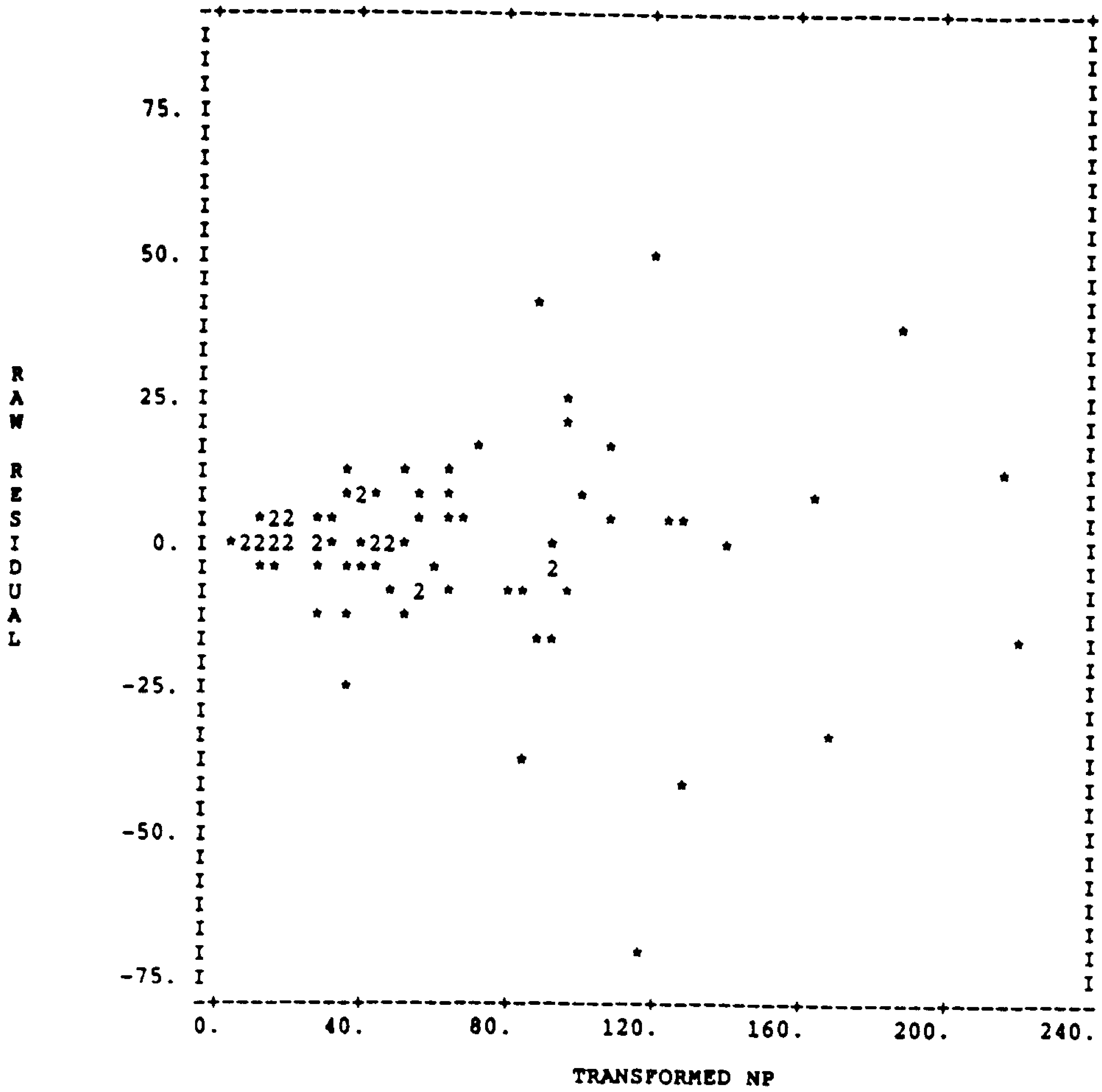


FIGURE 9.9(D)
RESIDUAL PLOT AGAINST TRANSFORMED NP
THEORETICAL MODEL D

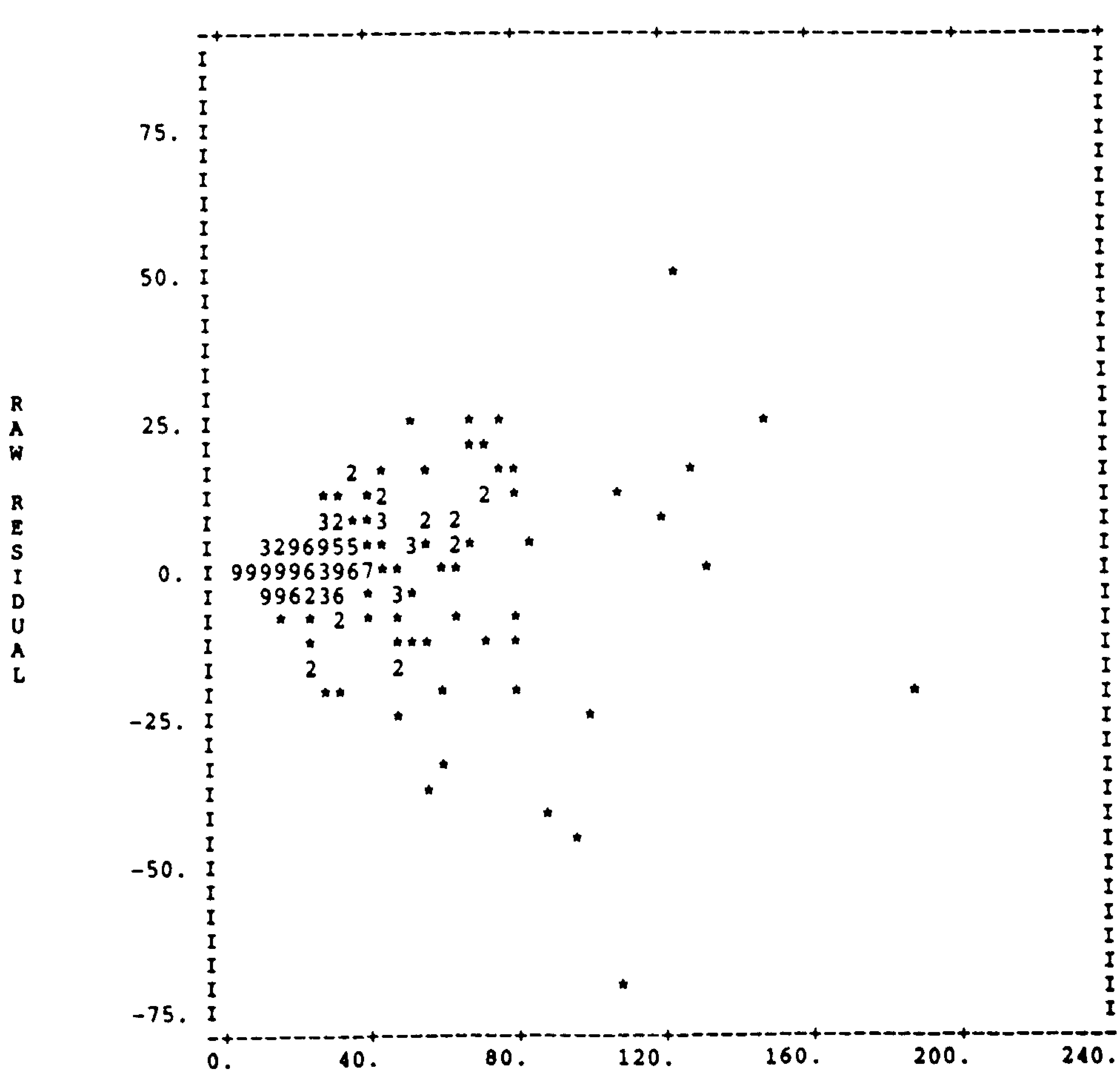
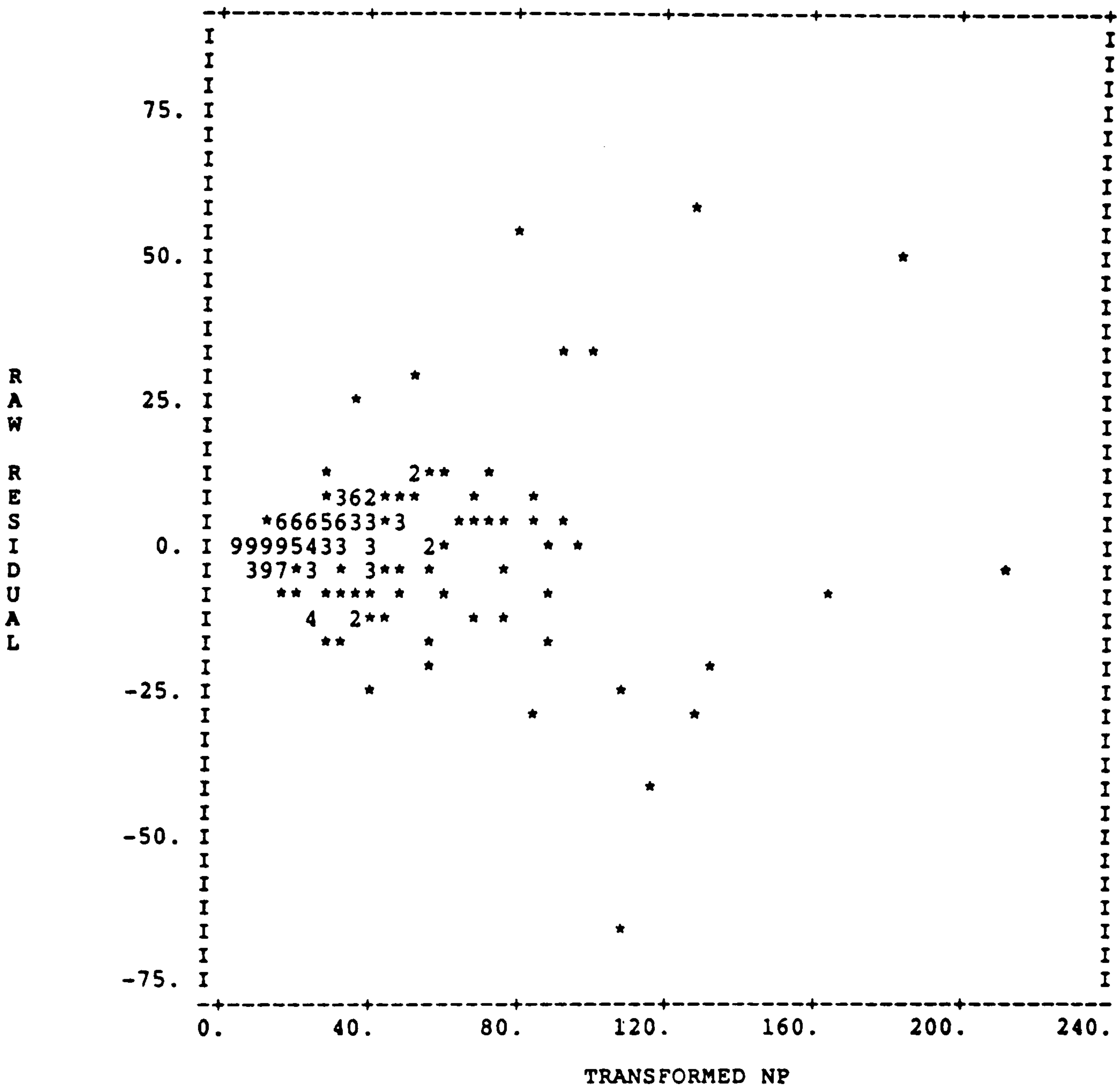


FIGURE 9.9(E)
RESIDUAL PLOT AGAINST TRANSFORMED NP
THEORETICAL MODEL E



increases. This indicates that the variance function is to some extent dependent of fitted values.

The residual versus fitted values transformed can also be used. With GLM of binomial errors, a scale for fitted values which is (2 inverse(sin))[square root(fitted values)] is proposed. This can be used to detect isolated points which have large residuals, a general curvature, indicating unsatisfactory covariate scales, link function or a trend in the spread with increasing fitted values. Figures 9.9(a)-(e) show the plot of all models. The pattern is the same as the above, but the extent of dispersion in plot of the residual against fitted values is reduced. The variance function check is not satisfactory but inview of the problem associated with statistical testing and in view that this problem will not invalidate the modelling no further testing is undertaken.

9.4.6 **OUTLIERS** -

Outliers are defined as the observations which may be separated in some way from the remainder of the data (332). The potential outliers in regression may have extremely large residuals and do not fit with the pattern of the remaining data points. Outliers need to be given careful considerations to determine the reasons for the fluctuations between the observed and predicted values of the response variables (333). Outlier must be examined and tested and decision made whether to exclude or include the observations. Outlier may arise because of the nature of the data, which may not necessitate their removal, unless a theoretical argument can be strongly presented to delete such observations. Another and more serious cause is outliers as a result of recording error which must be corrected. Outliers due to measurement error in this study may be difficult to detect because of the absence of precious empirical findings which can be used to validate the measurement. In multiple regression the presence of multiple unsual points exist if one or more of the following is present (334):-

i. That there is an outlier in the response variable (high residual).
ii. That there is a high leverage point in the explanatory variables, which mean there is a point that lies far out in the factors space.
iii. That there is a point which is influential either in respect of the model fit or the estimation of parameters.

GENSTAT report on the first two by listing:-

i. Any standardized residuals whose values is greater than the value c corresponding to probability 1/d being exceeded by a standard normal deviated, where d is the number of residual degree of freedom.
ii. Large values of leverage whose value is greater than c x k/ n where k in the number of paramemters and n is the number of units in the data.

The report by Genstat is however intended only to warn about potential unusual points but does not provide statistics to be tested. Cook's D statistic is also a useful diagnostic tools to weed out unusual points. The RKEEP directive of GENSTAT will allow the statistics to be calculated by keeping the leverage value and the fitted value after every fit. Cook's D is defined in equivalent from viz, (335):-

---

Di= [(Si)**2] * wi/k

Where Di = Cook statistics for 'i'th unit; Si =Standardized residual for the ith unit k = The number of parameters in the model.

Wi = li/(1-li) for the 'i'th unit

where li=leverage values of the 'i'th unit

The leverage and residual warning from GENSTAT and Cook's statistic are used to detect outlying cases. If the Di for that ith value is more than 1 then the unit is a candidate for removal from the data set. Unit/s which have high leverage, large residual and large Cook's statistics is given in Appendices E.1-5 for all models. The data sets were then checked, it was found that all outliers may fundamentally arise due to the nature of the data and thus their removal is not warranted.

FIGURE 9.10(A)
RESIDUAL PLOT AGAINST NORMALISED ORDERED RESIDUAL
THEORETICAL MODEL A

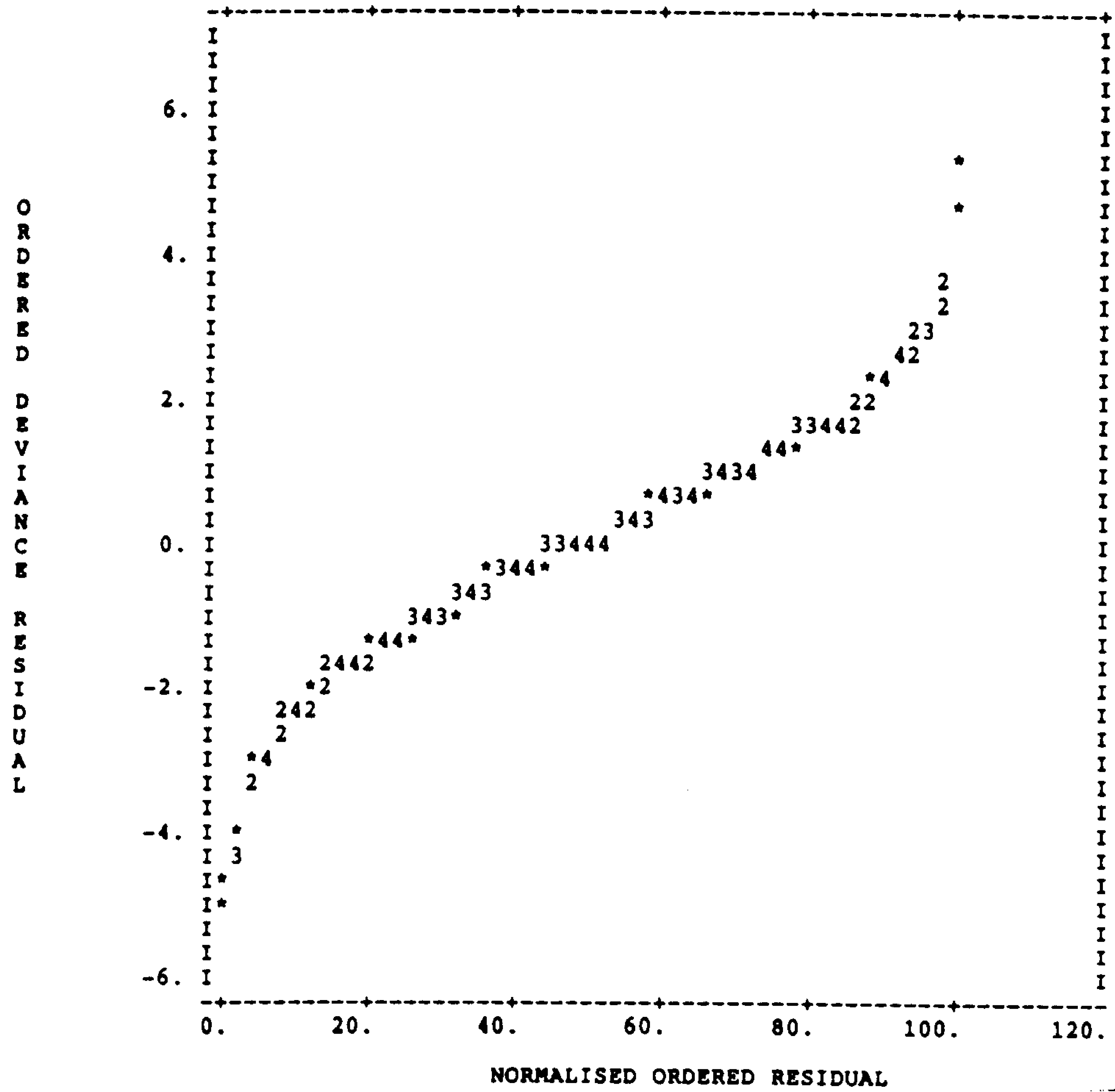


FIGURE 9.10(B)
RESIDUAL PLOT AGAINST NORMALISED ORDERED RESIUDAL
THEORETICAL MODEL B

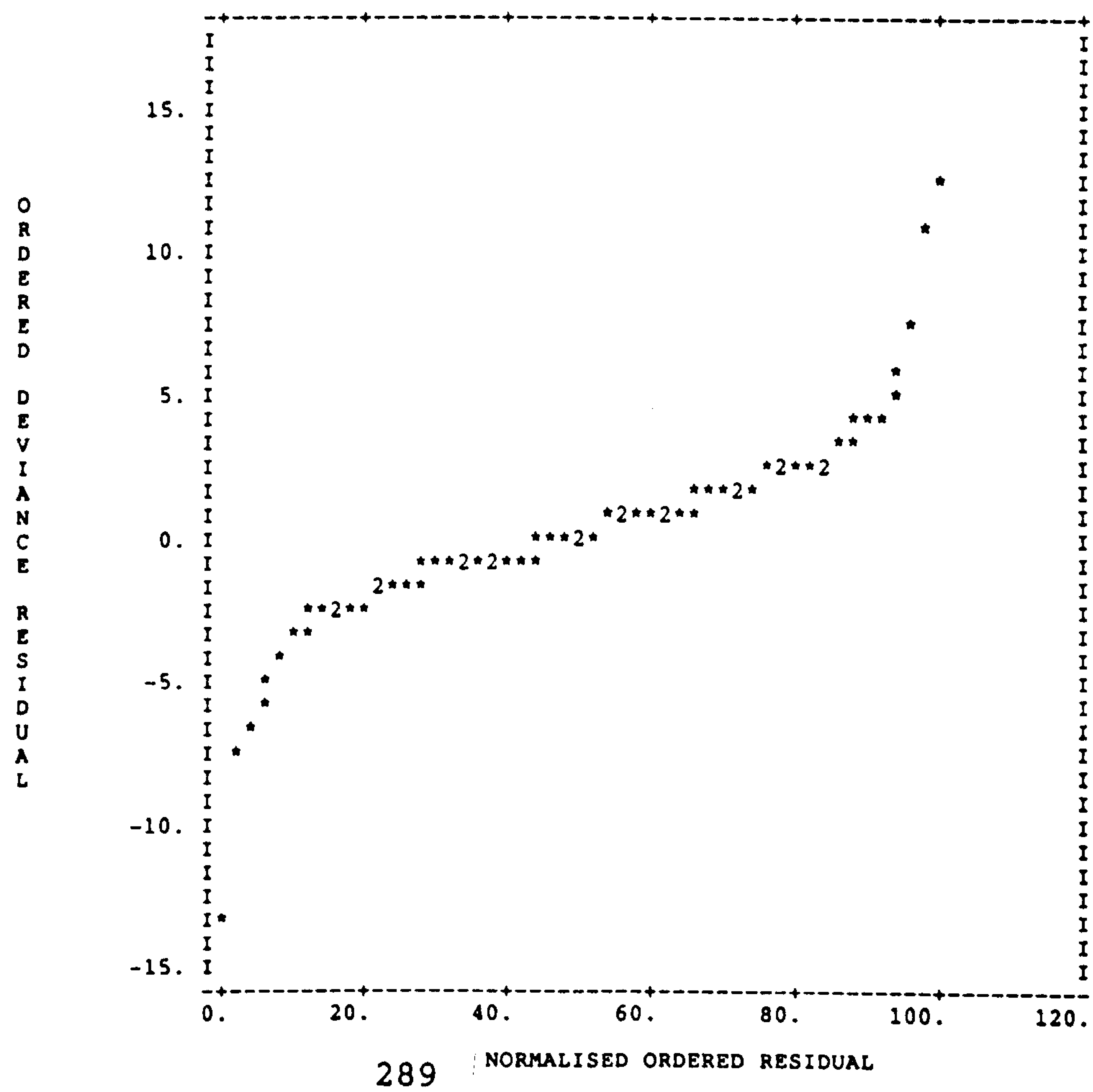


FIGURE 9.10(C)
RESIDUAL PLOT AGAINST NORMALISED ORDERED RESIDUAL
THEORETICAL MODEL C

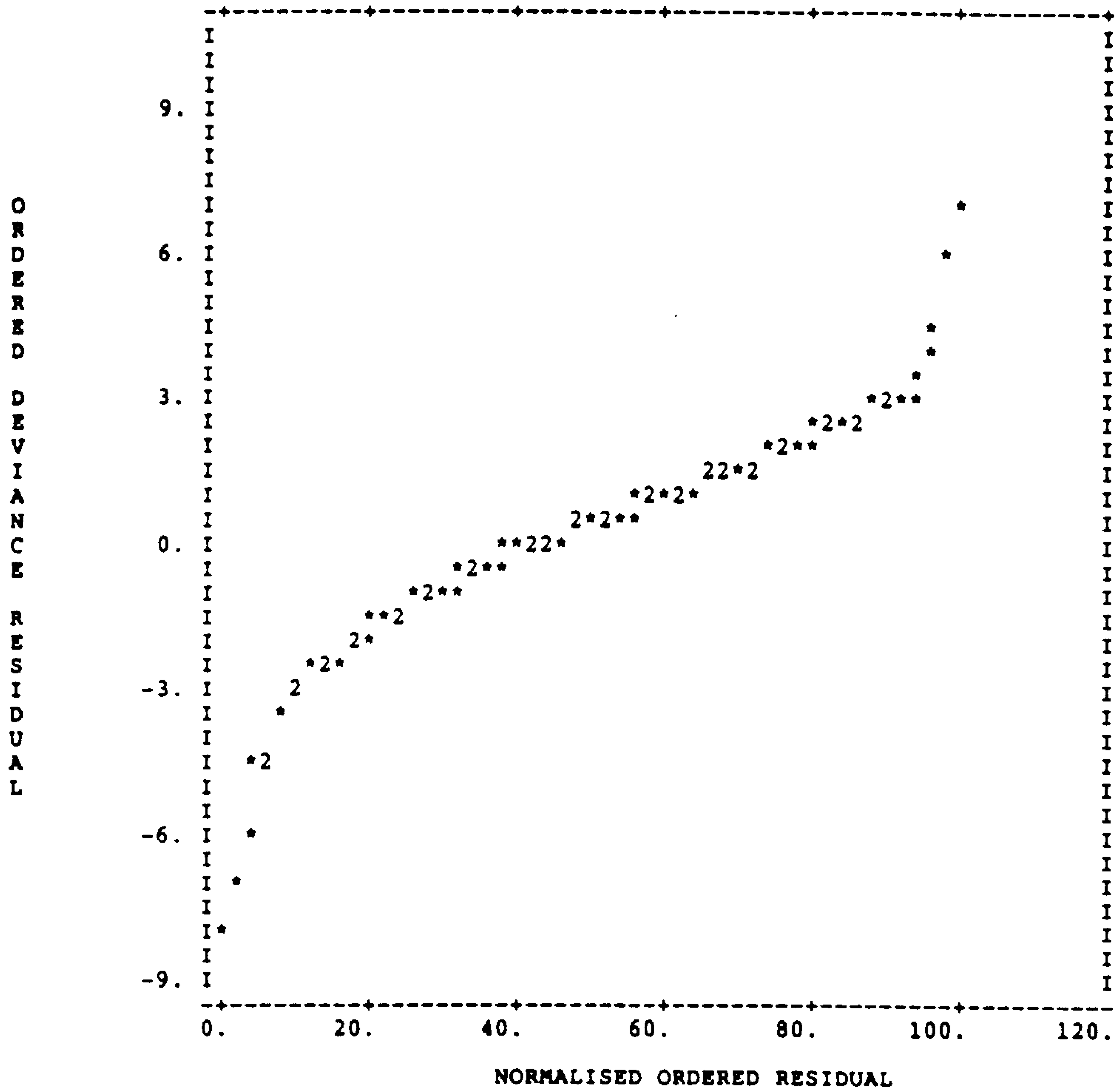


FIGURE 9.10(D)
RESIDUAL PLOT AGAINST NORMALISED ORDERED RESIDUAL
THEORETICAL MODEL D

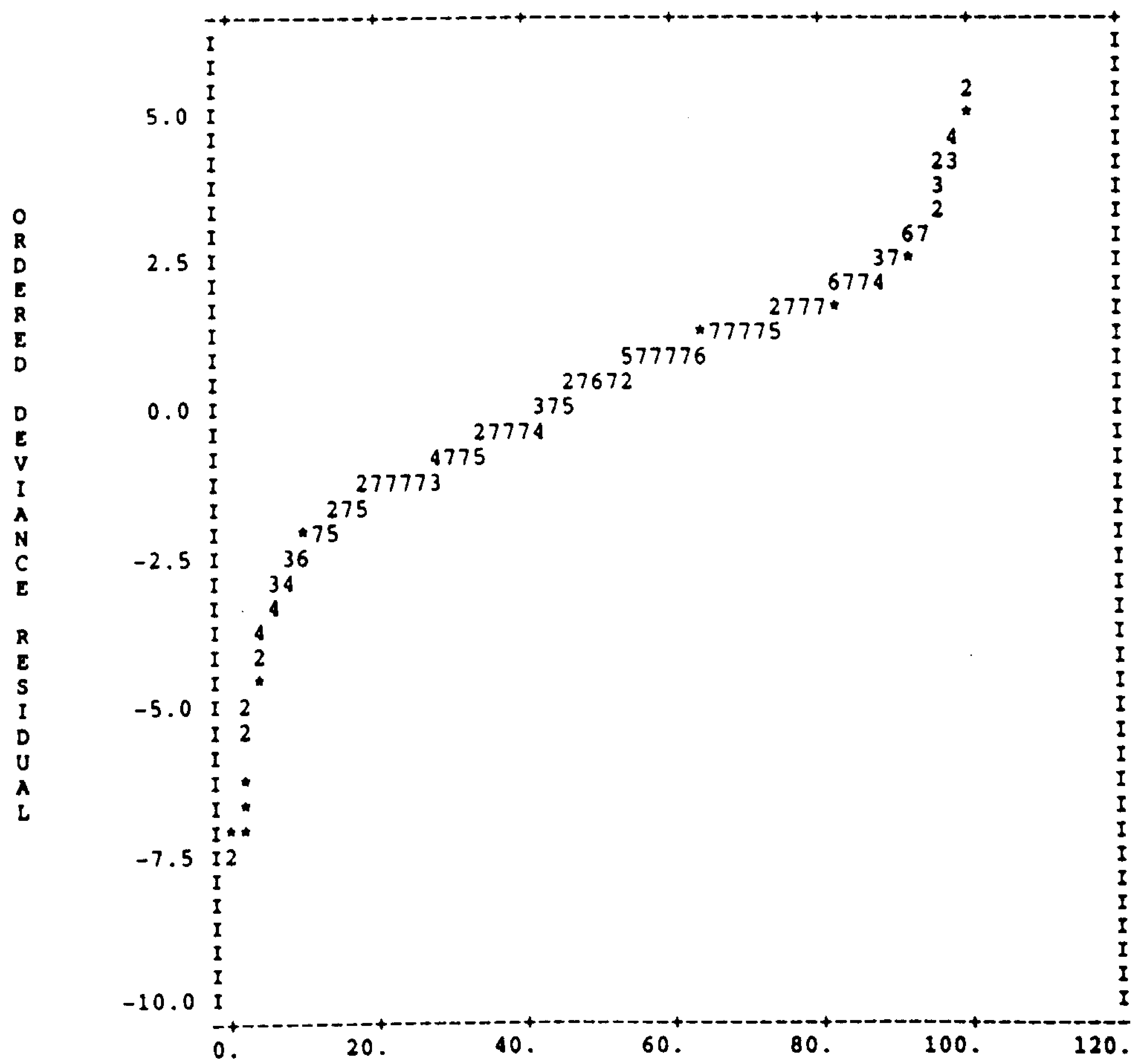
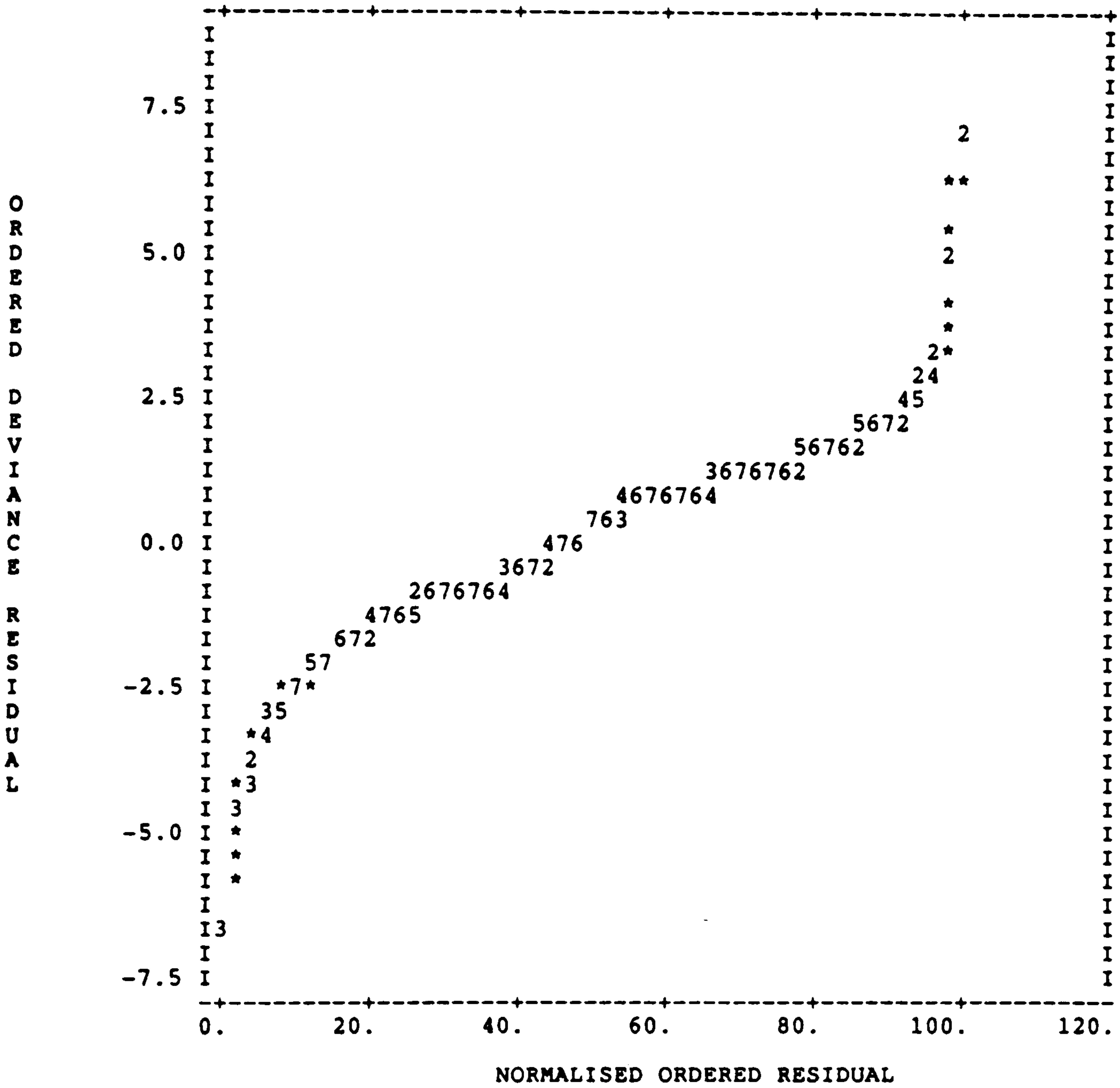


FIGURE 9.10(E)
RESIDUAL PLOT AGAINST NORMALISED ORDERED RESIDUAL
THEORETICAL MODEL E



The plot of ordered standardized residual against expected normal order statistics (Figures 9.10 (a)-(e)) is also used to detect the extent of influential observation. Extreme influence then appear at the ends and if unduly large deviate from the main trend. An important assumption is that the residuals (only) should at least be normally distributed. The plots shows a few points which is outlying in the factor space and which have been diagnosed by the statistics concerned.

9.4.7 **OTHER CONSIDERATIONS -**

The following are other considerations which have not been fully taken into account during model checking for reasons dealt with in respective items.

i. INDEPENDENCE OF OBSERVATIONS AND ERROR TERM

The assumption of independent or uncorrelated observations is more relevant in time series data (320) but still has to be considered. While a single error term in the error structure should exist in the data, it is not easily overcome. According to McCullagh and Nelder, both assumptions in practice can be somewhat less of a problem than what they might appear to be. Independence of observations in this study has been discussed in the section on activity sampling methodology. Wetherill (336) described several examples in classical linear models in which the above assumptions are not fulfilled. The problem of a single error structure has not been fully overcome and it will not be validated in this research because of the complexity of the problem. For example the independant variable in the model, may well be a normally distributed as against the binomial response variable.

ii. NORMALITY TESTING

Wetherill (337), noted that normality testing may not be undertaken, if the distribution of disturbances is known. However in many circumstances at least 'near' normality exist and thus the serious effect of deviation from normality needs to be determined. It is clear from the above argument that normality testing is not needed because of the principle associated with data collection which is based on binomial theorem. Since the statistical methodology to undertake analysis is available, the binomial distribution should be used to calculate the error distribution. Normality testings such as the Shapiro-Wilk (338), the Empirical distribution functions, D'Agostino (339) and Shapiro-Francia (340) tests will not be needed. The GLIM package also includes a macro routine for this test using the Shapiro-Francia test with the statistics W (341).

iii. MODEL SPECIFICATION ERROR

Model misspecification is a situation in which one or more of the following cases occur:-

a. The use of inappropriate functional form

b. The omission of one or more relevant variables

c. The inclusion of irrelevant variable

Functional form is associated with linearity assumption and has already been discussed. Error pertaining to (b) and (c) are related to theory and has been dealt with earlier. The theoretical model in this research (partial model) can be said to have a probability of inheriting error in model specification. Since a complete causal model is non-existent, the error cannot be discounted. The model developed will be tested and verified by the data and will only be a near approximation of reality to describe the complex interrelationship of factors influencing productive time at the site level.

iv. MULTICOLLINEARITY IN GLM

One of the assumption in classical linear regression is that no perfect collinearity (no independent variable is linearly related) exists with one or more of the other independent variables. Three sources of the problem are as follows:- (342)

a. Due to the physical constraints of the model or population
b. Due to sampling techniques
c. Due to over defined model

This problem has been widely discussed and no simple solution has been found. A few points noted by Berry and Feldman (343) is worth mentioning:-

a. Even with a high degree of multicollinearity, it does not violate the regression assumption.
b. Multicollinearity exist in degree and the degree

determines how important the problem is posed.

c. Multicollinearity increase the standard errors of the coefficient estimator and thus its major effect is on significance tests and confidence intervals for regression coefficients. Confidence interval for coefficients tend to be very wide while the t statistics tend to be very small.

Thus the problem is in the degree of multicollinearity and its consequence on the regression coefficient and its t values. In practice the problem arises from most of the three outlined sources.

Multicollinearity has always been discussed in terms of its influence on the Ordinary Least Square (OLS) estimates in classical regression. There is as yet no perfect way of overcoming the problem of multicollinearity even when using classical regression. The simplest method is to analyse the correlation between two variables, and if the correlation is high according to some predefined cut off value (say 0.8), then collinearity may exist. However this is unsatisfactory because the cut off value is very difficult to define and the bivariate correlation may not detect the multicollinearity with other independent variables (327). Another suggested method is to regress each independent variable against the rest of the independent variables and to measure the 'R squared' (coefficient of multiple determination). If 'R squared' is greater or equal 0.80 than existence of multicollinearity may be prominent. Wetherill (344) proposed another procedure in dealing with multicollinearity including creating condition number, condition index and using principal component regression, latent root regression and ridge regression. McCullagh and Nelder (345) discussed this problem specific to GLM with MLE estimator. This problem is solved partially thorugh the process of aliasing. Aliasing means that if a parameter is related in some form to another, then the parameters will be treated as having no influence because its influence is measured by the other parameter to which it is aliased. Aliasing consider not only linear dependencies of the particular data set, but also of the characteristics of the model and the functional relations of covariates.

Thus procedures in GENSTAT and Glim already take into account to some degree the problem of collinearity, by aliasing a particular variate. The process of model checking in Section 9.4.1 already takes into acount to some extent the multicollinearity problem and for the purpose of data modelling of data in this research this problem has been examined and treated appropriately.

9.5 MODEL SELECTION

The only problem left in modelling the influence of variables on productive time attributes is the choice of variables or covariates to be included in the systematic part (TERMS) in the model. For the selection to be satisfied the model has to be an optimum one, striking the balance between the improvement in the goodness of fit to the data and the additional complexity created by additional term in the model. The goodness of fit is the measure of how best the terms in the model fit the data. An optimum model in the context of the given data will probably be a clustered one (346) and only theoretical argument can select the best optimum model given the data. This is the main purpose of data analysis using statistical methodology, as a tool and not as an end to the process.

Model selection in this research is defined as the selection of subset/s of variables that will fit the data as well as if all the variables are used.

9.5.1 MODEL SELECTION IN GLM - SOME NOTES ON THE DIFFERENCES BETWEEN THE CLASSICAL LINEAR REGRESSION (CLR)

In CLR, using the Ordinary Least Squares (OLS) estimates, 'R squared' (coefficient of multiple of determination) measures the percentage of the variation in the dependent variables which is explained by the variations in the dependent variables taken together. In GLM using MLE estimates, only the deviance is produced (318). For the binomial model, scaled deviance is produced and is defined as:-

---

$-2\log(lc/lf)$

where

lc = likelihood of the current model

lf = likelihood of the full model given the data

The deviance statistic is a measure of the goodness of fit, same as 'R squared'. Schroeder et al (347) emphasized that although 'R squared' is of interest, it is not the sole determinant of a regression result. In fact maximization of 'R squared' is not the purpose of CLR analysis. In this research, the minimization of the deviance is not the sole purpose, since it has been accepted that not all variables have been measured.

Adjusted 'R squared' defined as the explantory power of regression induced by the inclusion or exclusion of a term (347) has been used to find the best subset of variables in CLR. In GLM using GENSTAT the residual deviance (scaled deviance) is the statistics for such measure. Baker and Nelder (348) noted that the assessment of goodness of fit of a GLM requires the scaled deviance with its associated degree of freedom to be matched against a theoretical distribution which represents its sampling distribution if the model is true. For the binomial distribution, the scaled deviance is known to be distributed as chi-squared only assymptotically. For binary data, the absolute deviance is completely uninformative about the goodness of fit. They suggested the difference of the deviances, which expresses the effect of adding/deleting a term to the model is used. In addition no p (confidence interval) values shall be attached to the ratio of the deviances and the corresponding chi-squared value should be regarded as a general guide in assessing the goodness of fit. Thus we rely on chi-squared statistics for testing the significance of differences between deviances of subsets of variables.

9.5.2 **PROCEDURES AND TEST IN SELECTION -**

GENSTAT allow selection of optimum model by invoking the STEP directive after the MODEL and FIT directive have been invoked (349). The STEP directive is similar to stepwise regression. It will drop/add one term at a time. Using the OUTRATIO and the INRATIO option, a term may be added/deleted if it satisfies a certain criteria.

The criteria is based on the deviance/variance ratio (DR). For the OUTRATIO it is

$$\{(s1-s0)/(d1-d0)\}/\{s0/d0\} > \text{OUTRATIO}$$

For the INRATIO it is

$$\{(s0-s1)/d0-d1)\}/\{s1/d1\} > \text{INRATIO}$$

Where

s0 = Residual of deviance of current model

s1 = Residual of deviance of model after making a term change

d0 = Residual degree of freedom of current model

d1= Residual degree of freedom after making a term change

The OUTRATIO and the INRATIO is set to the value of chi-squared statistics with 1 degree of freedom at the significance level of 5 percent, which is 3.841 (350). This ratio is high and is purposely set due to the problem of approximations with binomial model. If any term when the STEP directive is invoked dropped temporarily which has the deviance ratio greater than the OUTRATIO, then the term in the model which reduces the residual mean deviance will be dropped. This means that for every cycle only one term will be dropped. If no term is dropped, then the term that most reduces the mean residual deviances when added temporarily, will be added permanently if the deviance ratio is greater the INRATIO. This simply means as follows:-

i. If by adding a term, the increase in deviance is less than the chi-squared statistics, then the term is not significant and the term is not worth adding to the model.

ii. If by adding a term, the increase in deviance is greater than the chi-squared statistics, then the term is significant and the term is worth adding to the model.

iii. If by deleting a term, the decrease in deviance is less than the chi-squared statistics, then the term is not significant and the term is worth deleting from the model.

iv. If by deleting a term, the decrease in deviance is greater than the chi-squared statistics, then the term is significant it should be retained in the model.

9.5.3 PARAMETER ESTIMATION - TESTING OF SIGNIFICANCE -

The unknown parameters have to be estimated and a measure of their accuracy has to be obtained given the model selected from the above process. Estimation can be done by defining a measure of goodness of fit between and data and a corresponding set of fitted values generated by the model and choosing the parameter estimates to minimize the chosen goodness of fit criterion. To test the hypothesis that the true regression coefficient differs from zero, a two sided tests procedure will be done on the individual parameters value.

The null hypothesis is that
THE REGRESSION COEFFICIENT EQUALS BETHA(0) (CONSTANT) AGAINST THE ALTERNATIVE HYPOTHESIS THAT IT IS NOT EQUAL TO BETHA(0).

H(0):BETHA(0) VS H(A): BETHA(J) IS NOT = 0

The t ratio will be used to test this. If t ratio is greater than the t statistic, the null hypothesis is rejected in favour of the alternative hypothesis. In so doing we can conclude that the parameter is significant to the model. Baker and Nelder (351), again emphasized that the t distribution is exact for the classical linear model, for GLM with other distribution, it is only justified by asymptotic theory. Again no attempt should be made to place exact p (confidence intervals) values. They suggested that a t-value for less than 1.00 is not significant and greater than 3.00 is significant. When t value is between these bounds, the change in deviance of the model after deleting the term should be assesssed to detemine the significance of the parameter to the model. They also emphasized that tests on individual t values should take into account correlations of estimates. When they are substantial, the test can be misleading, reflecting again the problem of collinearity and the model selection procedure above should be adhered to.

9.5.4 **FIRST ORDER INTERACTION -**

Interaction of variables is associated with the term additivity. Interaction terms in regression are products of two or more predictor variables. Additivity is the assumption that the influence of an independent variable does not depend on one or more of the other independent variable. The key question to ask in deciding if there is reason to expect non-additivity, is whether for each independent variable, the slope of the relationship between the independent and dependent variable is expected to vary depending on the 'context' (352). The problem associated with non-additivity is that the accuracy of the predicted values could be prejudiced. Nevertheless most research data is expected to contain one or more significant interaction terms, although Lewis-Beck (353) has hinted that the ascertainment of additivity of relationship may be attempted by testing for the absence of significant interaction effects in data. The problem will be that with a large number of variables, most statistical packages cannot accommodate more than a certain number of terms or there is restriction in the number of interaction terms that can be included. Thus the overall testing as suggested by Lewis- Beck cannot be done. Nevertheless some testing of the effect of interaction terms can be done. The problem of non-additivity can be overcome by creating additional multiplicative terms if an interaction effect is significant to the model. Additivity of systematic effects can be then specified to hold on to a transformed scale when necessary for GLM (320). Although interpretation is more difficult, its presence must not be regarded as invalidating regression assumptions. The possibility must be recognized and the inclusion of significant interaction terms will thus suffice for the purpose of this research.

Interaction terms if need to be included need not be interpreted as being a problem. They are useful to be considered when it is believed that the effect of predictor variable or the response depends on the values of other predictor variables (325). Interaction terms clearly allow more opportunity for independent predictor variables to exhibit joint effects with other predictor variables. Several interaction terms involving the predictor variables can be included in the modelling but should not be inserted routinely for several reasons:-

i. The number of possible interaction terms can be large as has been discussed thus resulting in a complicated model and may not substantially improve the fit to the data.

ii. Interaction terms sometimes repeat information provided by predictor variables. If redundancy induced by interaction terms is too strong, the coefficient estimate for predictor variables can be distorted (325).

Therefore to include interaction terms in the model, the choice of interaction terms will depend on the following:-

i. The interaction terms is know a priori (325).

ii. That the interaction terms is accompanied by both corresponding linear terms (354).

For condition (i), little is known about the effect of interaction terms from previous studies. Thus to insert even first order interaction without strong reasons may lead to much problems in the choice of optimum model. For condition (ii), the presence of interaction terms indicates that the effect on the response of changing one of the variable depend on the setting of the other and vice cersa. The interaction terms is generally interpreted as accounting for variation in the response variable OVER AND ABOVE the variation accounted for by the predictor variables (354). Its interpretation in the absence of either or both predictor variables is problematic. Genstat can automatically helped to satisfy the second condition to some extent by accounting the interaction terms as being marginal to predictor variables (355), which mean that in the process of model selection, the predictor variables will not be dropped if the interaction term is still present during the modelling. Genstat will not marginalize interaction terms whose predictor variables are both quantitative. To obtain interaction term for two quantitative variables, cross product term is calculated by multiplying the two predictor variables, and obtaining new value which are treated as if it is a new predictor variable. Thus problems may arise when an interaction term of 2 quantitative predictor variables is not dropped but the predictor variables are dropped first.

To overcome the problem and to reduce the number of interaction terms to be tested in addition to the possibility that the cross product term of quantitative varaibles carry the same information as the main effect, the interaction terms of 2 quantitative variables will be correlated with all predictor variables, and signs of high linearity will warrant deletion of the interaction terms and reduce the potential problems that may arise.

GENSTAT can only automatically take into consideration up to three factors interaction but because of the problem of sufficient CPU time available to model the data, only first order (2 factors) interaction will be considered.

9.6 MODEL SELECTION - THEORETICAL MODEL A

9.6.1 MAIN EFFECTS VARIABLES

Model selection of main effects variables only as the first step in model selection were undertaken for all theoretical models in accordance with the above procedures. Appendix F.1 summarized the first model selection of all the variables in model A.

Initial fitting of the data with 10 variables, give a mean residual deviance of 6.702 for model A. After the selection process, the deviance is decreased to 6.876: a decrease of 0.174 of the deviance. However from the original 10 variables included in the model, only 5 have been selected as significant and the selection process has shown that a parsimonous model of 5 variables only is needed to describe the pattern in the data. Although the mean residual deviance has been decreased slightly indicating a lesser fit, it is only very marginal to the original residual deviance which in turn increase t values of parameter estimates. In comparison to the mean residual deviance of the null model, the fit of the model with five variables can be said to have not explained about 46 percent of the variation in the residuals. This is calculated by dividing the mean residual deviance against the mean total deviance.

The parameter estimates of all 5 variables is more than 3.00 and thus for the 5 variables the alternative hypothesis for parameter estimation is accepted and all the variables are significant in the model. In so doing the remaining 5 variables are not accepted as significant to model A. Table 9.3(a) shows the summary of the results of the modelling for this model.

Usually in most analytical analysis, some form of ranking on the contribution of a particular variable is formed. Table 9.3(b), is the result of the model fitting before the selection of the parsimonous model. The mean residual deviance of the model when dropping a variable is given. Note that the lack of fit of the model implied by an increase in the mean residual deviance can be used to rank the contribution of a particular variable. In so doing we are implying that the measure of the contribution of the variable can be made by excluding it from the model and note what happens to the fit of the model.

From this it can be concluded that the ranking of the variable are x19, x5b, x18, x12b, x1 which are significant to the model. X19 give the largest variation in the model fit when dropped temporarily from the model, followed by X5B.

9.6.2 FIRST ORDER INTERACTION -

The first selection reduces the model to 5 variables. The second step in selection is to determine whether or not the interaction effects between the variables are significant to the model. With 5 variables, the possibility of all terms to be included in the model is 32. Therefore there are 15 possible terms in the model. However correlation between interaction terms from quantitative predictor variables as listed in Table 9.3(c), shows that all of the interaction terms have high correlations with the predictor variables and therefore these interaction terms will not be tested as they contain as much information as in the predictor variables concerned. Thus only 9 terms will be tested including 4 interaction terms.

The results of the second stage of selection is summarized in Appendix F.1. The original fit of the model with 5 variables is 6.876 and the fit with 9 terms is 6.255. The STEP directive was invoke again as in the first selection and only 6 terms are left in the model after the second selection. The fit of the model is now increased to 6.411. Comparing this with the null model, by about 43 percent the variation in the data has not been explained, as compared to about 46 percent in the first selection. All the terms t values is significant. Table 9.3(d) show the summary of results of the fitting.

TABLE 9.3(a)
MODEL SELECTION
MAIN EFFECTS - MODEL SELECTED

```
*** Residual mean deviances ***

        6.700    Adding   X14
        6.750    Adding   X16
        6.770    Adding   X7
        6.786    No change
        6.788    Adding   X17
        6.789    Adding   X9
        6.966    Dropping X1
        7.015    Dropping X12B
        7.632    Dropping X18
        8.596    Dropping X5B
        9.305    Dropping X19

VARIABLES DROPPED = X9, X17, X14, X7, C16
```

```
*** Summary of analysis ***
    Dispersion parameter is 1

                 d.f.     deviance    mean deviance
Regression          5        1518.      303.613
Residual          182        1235.        6.786
Total             187        2753.       14.723

Change              0           0.            *
```

```
*** Estimates of regression coefficients ***

                    estimate          s.e.            t
Constant             -0.5497        0.0773        -7.11
X18                -0.003552      0.000288       -12.31
X5B                 0.006747      0.000371        18.19
X19 2.00              1.0033        0.0469        21.37
X12B                 -0.0994        0.0143        -6.96
X1                   0.02196       0.00349         6.30
* MESSAGE: s.e.s are based on dispersion parameter
with value 1

MODEL SELECTED BASED ON MODELLING MAIN EFFECTS VARIABLES
ONLY

VARIABLES = +X1, +X5, -X12B, -X18, +X19
```

TABLE 9.3(B)

CONTRIBUTION OF THE SIGNIFICANT MAIN EFFECT VARIABLES TO MODEL A

MODEL X1,X12B,X18,X5B,X19

VAR DROPPED	MEAN RES. DEVIANCE WITHOUT THE VAR	% UNEXPLAINED RES WITHOUT THE VAR	RANK
X1	6.966	47.3	5
X12B	7.015	47.6	4
X18	7.632	51.8	3
X5B	8.596	58.4	2
X19	9.305	63.2	1

TABLE 9.3(c)
CORRELATIONS OF QUANTITATIVE INTERACTION TERMS

	X18	X5B	X18X5B	X12B	X18X12B	X5BX12B	X1	X18X1	X5BX1
X18	1.000								
X5B	0.154	1.000							
X18X5B	0.785	0.380	1.000						
X12B	0.103	0.189	0.050	1.000					
X18X12B	0.964	0.125	0.734	0.182	1.000				
X5BX12B	0.137	0.922	0.308	0.420	0.140	1.000			
X1	0.201	0.231	0.132	0.746	0.228	0.381	1.000		
X18X1	0.969	0.127	0.758	0.134	0.950	0.127	0.267	1.000	
X5BX1	0.170	0.901	0.335	0.331	0.155	0.919	0.473	0.174	1.000
X12BX1	0.123	0.175	0.057	0.912	0.189	0.400	0.896	0.178	0.401

TABLE 9.3(d)
MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED MODEL
MODEL SELECTED

```
* MESSAGE: Term X5B can not be dropped
  because it is marginal to term X5B.X19 which
  is in the model

*** Residual mean deviances ***

      6.314    Adding   X18.X19
      6.333    Adding   X1.X19
      6.411    No change
      6.444    Adding   X12B.X19
      6.589    Dropping X12B
      6.620    Dropping X1
      6.786    Dropping X5B.X19
      7.192    Dropping X18
      9.250    Dropping X19
VARIABLES DROPPED - X1.X19,X12B.X19,X18.X19

FINAL MODEL :

.^*Constant + X18 + X5B + X12B + X1 + X19 + X5B.X19\*

*** Summary of analysis ***
    Dispersion parameter is 1

                d.f.     deviance     mean deviance
Regression         6        1593.        265.464
Residual         181        1160.          6.411
Total            187        2753.         14.723

Change             0           0.              *

*** Estimates of regression coefficients ***

                  estimate        s.e.        t
Constant           -0.6542      0.0787    -8.32
X18              -0.003415    0.000289   -11.83
X5B               0.007390    0.000380    19.45
X12B               -0.0892      0.0143    -6.23
X1                 0.02330     0.00350     6.66
X19 2.00            1.2632      0.0561    22.53
X5B.X19 2.00      -0.01879     0.00217    -8.68
* MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

9.6.3 OPTMIMUM MODEL FOR THEORETICAL MODEL A -

The result of the modelling have shown that the weekly productive time is influenced significantly by 5 main variables and 1 first order interaction variables. Thus the hypothesis that productive time is influenced by 10 variables has been discounted. The alternative hypothesis that 5 of the variables will explained the variation as good as when the 10 variables are measured and analysed is accepted. The significant variables and their interaction have helped to explain the variation by about 57 percent of the variation in the data.

The model is now advanced as:-

$$Ap = a + x19 + x1 + x5b - x18 - x12b - x5b.x19$$

Weekly productive time is thus a function of floor level; task variabilities; trade variabilities; management team influence; and bad weather. The interaction between floor level and management team indicate that it is significantly influencing productive time by showing that the values of management team presence depends on the floor level and vice versa. Only two of the variables are positively influencing weekly productive time model.

Implication from this finding indicate that weekly manpower productive time is largely influenced by the differences in where they are working. The data which have been seggregated into various floor indicate that floor higher up the ground will have more productive time. This is against the norm in estimating for work, when multiplicative value is added for work higher up the ground floor. Site observation for this study confirmed that the probability of higher productive time proportion in floor above the ground floor, but when the floor influence was examined on its own, the differences between the first and second floor is only very marginal. Based on this, the only reasonable explanation is that work above ground level is less interrupted. Since most preparation work is done at the ground level when an operative was observed undertaking such work he was coded as working at ground level, eventhough he may actually be working at the first floor. However significantly the result from this modelling also indicate that management team depends on the floor factor to induce such influence. A major contradiction in the direction of influence of task variabilities: its influence was hypothesized as negative but the modelling yield a positive influence. This could only be explained by the fact that when operatives are occupied with task, its productive time will be increased.

9.7 MODEL SELECTION - THEORETICAL MODEL B

9.7.1 MAIN EFFECTS VARIABLES

Appendix F.2 summarized the first model selection of all the variables in model B. Initial fitting of the data, give a mean residual deviance of 10.46. After the selection process this deviance is decreased to 10.48, a decrease of 0.02 of the deviance. From the original 8 variables included in the model, only 7 variables were tested because variable x15 was deleted during the model checking process. From the 7 variables, only 4 have been selected as significant and the selection process has shown that a parsimonous model of only 4 variables is needed to describe the pattern in the data from the 7 variables. Although the mean residual deviance has been decreased slightly indicating a lesser fit, it is only very marginal to the original residual deviance. In comparison to the residual deviance of the null model, the fit of the model with five variables can be said to have not explained about 42 percent of the variation in the residuals calculated in the same way as in model A.

TABLE 9.4(a)
THEORETICAL MODEL B
MODEL SELECTION
MAIN EFFECTS - MODEL SELECTED

*** Residual mean deviances ***

*** Residual mean deviances ***

10.40	Adding X8
10.41	Adding X7
10.48	No change
10.65	Adding X1
11.15	Dropping X18
11.36	Dropping X14
12.07	Dropping X13
22.12	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	4	1003.9	250.97
Residual	63	660.3	10.48
Total	67	1664.2	24.84
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.4403	0.0365	-12.07
X14 2.00	-0.2319	0.0285	-8.14
X19 2.00	0.9626	0.0356	27.02
X13	0.05305	0.00503	10.56
X18	-0.0002931	0.0000403	-7.28

* MESSAGE: s.e.s are based on dispersion parameter with value 1

MODEL SELECTED BASED ON MODELLING MAIN EFFECTS VARIABLES ONLY

VARIABLES = X14, X19, X13, X18

TABLE 9.4(B)

CONTRIBUTION OF THE SIGNIFICANT MAIN EFFECT VARIABLES TO MODEL B

MODEL: X18,X14,X13,X19

VAR DROPPED	MEAN RES. DEVIANCE	% UNEXPLAINED RES WITHOUT THE VAR	RANK
X18	11.15	44.9	1
X14	11.36	45.7	2
X13	12.07	48.6	3
X19	22.12	89.0	4

TABLE 9.4(c)
CORRELATIONS OF QUANTITATIVE INTERACTION TERMS

X13	1.000		
X18	0.632	1.000	
X18X13	0.619	0.961	1.000
	X13	X18	X18X13

TABLE 9.4(d)

MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED

TERM NOT DROPPED	MARGINAL TO
X18	X18.X14
X14	X19.X14
X19	X19.X14

TERM NOT ADDED	MARGINAL TO
X13.X14	X13
X13.X19	X13

*** Residual mean deviances ***

8.438	Adding X13
8.758	Adding X18.X19
8.799	No change
9.732	Dropping X14.X19
10.358	Dropping X18.X14

VARIABLES DROPPED :X13.X14,X18.X19,X13.X19,X13

FINAL MODEL:

Constant + X18 + X14 + X19 +X18.X14 + X14.X19

*** Summary of analysis ***

Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	5	1118.6	223.722
Residual	62	545.5	8.799
Total	67	1664.2	24.838
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.1473	0.0297	-4.96
X18	-0.001418	0.000133	-10.64
X14 2.00	-0.1344	0.0387	-3.47
X19 2.00	1.0141	0.0459	22.09
X18.X14 2.00	0.001383	0.000138	10.02
X14 2.00 .X19 2.00	-0.4992	0.0609	-8.20

* MESSAGE: s.e.s are based on dispersion parameter with value 1

The parameter estimates of all 4 variables is more than 3.00 and thus for the 4 variables the alternative hypothesis for parameter estimation is accepted and are significant in the model. In so doing the remaining 3 variables are not accepted as significant to model A.

Table 9.4(a) shows the summary of the results of the modelling for this model. The contribution of the variables is calculated in the same way as in model A. Table 9.4(b), is the result of the model fitting before the selection of the parsimonous model.

The variables x19, x13, x14, x18 are significant to the model. Again variable x19 contributed to the fit of the model very very significantly. Note that variable x15 was dropped in favour of x1 because of their high correlation. The selection process dropped x1 and thus it is safe to assumed that variable x15 is not significant to model B.

9.7.2 FIRST ORDER INTERACTION -

The first selection reduces the model to 4 variables. With 4 variables, the possibility of all terms to be included in the model is 16. Modelling of only first order interaction will include only 10 possible terms in the model. However, Table 9.4(c) shows that the correlation between x18x13 and its quantitative predictor variables is high and for this reason, its influence will not be tested, leaving only 9 terms for the second stage of selection.

The results of the second stage of selection is summarized in Appendix F.2. The original fit of the model with 4 variables is 10.48 and the fit with 9 terms is 8.452. The STEP directive was invoke again as in the first selection and only 5 terms are left in the model after the second selection. The fit of the model is now increased to 8.799. Comparing this with the null model, about 35 percent of the variation in the data has not been explained, as compared to about 42 percent in the first selection. All the terms t values are significant but variable x13 main effects variable has been dropped from the final selection of the model. Table 9.4(d) shows the summary of results of the fitting. The final model chosen contains 3 main effects variables and 2 first order interactions.

9.7.3 **OPTIMUM MODEL FOR THEORETICAL MODEL B -**

The result of the modelling has shown that the trade productive time is influenced significantly by 3 main variables and a further 2 first order interaction variables. Thus the hypothesis that trade productive time is influenced by 8 variables has been discounted and the alternative hypothesis that 3 of the variables will explain the variation better when the 8 variables are measured and analysed is accepted. The significant variables and their interactions have helped to explain the variation by about 65 percent ofthe variation in the data as compared to 58 percent with only main effects variables.

The model is now advanced as:-

$$Bp = a + x19 + -x14 - x18 - x14.x19 + x18.x14$$

Trade productive time is thus a function of floor level; trade type; bad weather ;the interaction between floor level and trade type; and the interaction between bad weather and trade type.

Implication from this finding is that the productive time of manpower when analysed by trade type is also largely influenced by the differences in where they are working, confirming again the large influence of floor level on productive time. Bad weather influence which is again analysed in this model is also significant. In addition the result from this modelling also indicates that the interaction between the floor factor and the trade type means that the floor factor depends on the trade type and vice versa and resulted in lower productive time at the higher floor. The interaction between weather influence and trade type means that the weather influence also depends on the trade type which is obvious because only some trade types will be working externally. Notably the direction of influence indicates that bad weather influence of trade within the control of the main contractor is positive. The implication from this is that although bad weather influence on its own is negative, the influence of bad weather relative to trade significance implies that only certain trade is affected by the weather. The positive influence indicate that those trades which are significant when not affected by the weather will influence productive time positively.

9.8 MODEL SELECTION - THEORETICAL MODEL C

9.8.1 MAIN EFFECTS VARIABLES -

The first model selection of all the variables in model C is as shown in Appendix F.3. There were 11 variables for model C but in model checking this is increased to 12 variables becasue variable x12b and x12a do not show a high correlation. Initial fitting of the data, give a mean residual deviance of 6.312 for model C. After the selection process this deviance is decreased to 6.380, an decrease of 0.068 of the deviance. Only 2 have been selected as significant and the selection process has shown that a parsimonous model of 2 only variables is needed to describe the pattern in the data from the 12 variables. Although the mean residual deviance has been decreased slightly indicating a lesser fit, it is only very marginal. In comparison to the residual deviance of the null model, the fit of the model with 2 variables can be said to have not explained about 57.5 percent of the variation in the residuals calculated in the same way as in model A.

The parameter estimates of the 2 variables; x19 and x10 is more than 3.00 and thus for the 2 variables the alternative hypothesis for parameter estimation is accepted and is significant in the model. In so doing the remaining

9 variables are not accepted as significant to model C. Table 9.5(a) shows the summary of the results of the modelling for this model. The contribution of the variables is done in the same way as in model A. Table 9.5(b), is the result of the model fitting before the selection of the parsimonous model.

From this it can be concluded that the ranking of the importance of the variable is x19 and x10 which is significant to the model. Again variable x19 contributed to the fit of the model significantly. Note that variable x12b and x12a are not selected and thus no new variable is added.

9.8.2 FIRST ORDER INTERACTION -

The first selection reduces the model to 2 variables, and the possibility of all terms to be included in the model is 4. Modelling of only first order interaction will include only 3 terms in the model and are listed in Appendix F.3 with the results. No new term is added to the model and thus no change in the result form the first selection is noted.

TABLE 9.5(a)
THEORETICAL MODEL C
MODEL SELECTION
MAIN EFFECTS - MODEL SELECTED

*** Residual mean deviances ***

6.284	Adding	X3
6.300	Adding	X2
6.325	Adding	X14
6.364	Adding	X1
6.380	No change	
6.434	Adding	X7
6.448	Adding	X5B
6.449	Adding	X6
6.461	Adding	X12A
6.464	Adding	X4
6.465	Adding	X12B
7.754	Dropping	X10
10.562	Dropping	X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7, X1, X6, X14, X3

Fitted terms: Constant, X19, X10

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	2	380.8	190.415
Residual	76	484.9	6.380
Total	78	865.7	11.099
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5519	0.0219	25.22
X19 2.00	0.6109	0.0343	17.81
X10 1	-0.3452	0.0326	-10.59

* MESSAGE: s.e.s are based on dispersion parameter with value 1

MODEL SELECTED BASED ON MODELLING MAIN EFFECTS VARIABLES AND 2 FACTOR INTERACTION AS DESCRIBED IN APPENDIX F.3

VARIABLES = -X10 +X19

TABLE 9.5(B)

CONTRIBUTION OF THE SIGNIFICANT MAIN EFFECT VARIABLES TO MODEL C

VAR DROPPED	MEAN RES. DEVIANCE	% UNEXPLAINED RES WITHOUT THE VAR	RANK
X10	7.754	69.9	2
X19	10.562	95.2	1

9.8.3 OPTMIMUM MODEL -

The result of the modelling have shown that the building element productive time is influenced significantly by only 2 main variables and no first order interaction variables. Thus the hypothesis that trade productive time is influenced by 11 variables has been discounted and the alternative hypothesis that 2 of the variables will explained the variation as good as when the 11 variables are measured and analysed is accepted. The significant variables and their interaction have helped to explain the variation by about 43 percent.

The model is now advanced as:

$$Cp = a + x19 - x10$$

Building element productive time is thus a function of floor level and design rationalization.

Implication from this finding is that the productive time of manpower when anaysed by building element is also largely influenced also by the differences in where they are working, confirming again the large influence of floor level on productive time. Elements which have some form of design rationalization applied were found to have much lower productive time. This contradicts the hypothesis and will be discussed in the conclusion, but it does show that the influence on design rationalization have again been questioned in as far as productive time is concerned.

However as can be seen the remaining 10 variables have not been chosen. The only valid explanation for this is that the classification of building element is too large, the productive time variation varies from 4 hours to 4270 per element, with an average of 603 hours per element. In addition variables which have been measured may not be a function of the building element productive time.

TABLE 9.6(a)
THEORETICAL MODEL D
MODEL SELECTION
MAIN EFFECTS - MODEL SELECTED

*** Residual mean deviances ***

4.911	Adding	X12A
4.917	No change	
4.923	Adding	X10
4.930	Adding	X12B
4.931	Adding	X5
4.965	Dropping	X2
4.990	Dropping	X14
4.997	Dropping	X3
5.000	Dropping	X6
5.057	Dropping	X4
5.274	Dropping	X7
5.330	Dropping	X19

VARIABLES DROPPED X12, X12B, X5, X10

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	7	504.	71.948
Residual	340	1672.	4.917
Total	347	2175.	6.269
Change	0	0.	*

ESTIMATES OF REGRESSION COEFFICIENTS

	estimate	s.e.	t
Constant	1.0535	0.0652	16.16
X4 2.00	-0.3389	0.0471	-7.20
X14 2.00	-0.2103	0.0387	-5.44
X19 2.00	0.4585	0.0382	12.01
X2	-0.003830	0.000830	-4.62
X6	-0.04239	0.00734	-5.77
X3	0.01493	0.00263	5.67
X7	-0.004888	0.000433	-11.28

* MESSAGE: s.e.s are based on dispersion parameter with value 1

TABLE 9.6(B)

CONTRIBUTION OF THE SIGNIFICANT MAIN EFFECT VARIABLES TO MODEL D

VAR DROPPED	MEAN RES. DEVIANCE	% UNEXPLAINED RES WITHOUT THE VAR	RANK
X2	4.965	79.2	7
X14	4.990	79.6	6
X3	4.997	79.7	5
X6	5.000	79.8	4
X4	5.057	80.7	3
X7	5.274	84.1	2
X19	5.330	85.0	1

TABLE 9.6(c)
CORRELATIONS OF QUANTITATIVE INTERACTION TERMS

X3	1.000								
X2	0.397	1.000							
X6	0.743	0.201	1.000						
X7	0.583	0.199	0.355	1.000					
X2X6	0.743	0.597	0.707	0.391	1.000				
X2X3	0.834	0.636	0.467	0.453	0.806	1.000			
X2X7	0.563	0.279	0.308	0.915	0.434	0.531	1.000		
X3X6	0.885	0.283	0.834	0.547	0.755	0.683	0.523	1.000	
X7X6	0.600	0.172	0.447	0.867	0.483	0.460	0.777	0.695	1.000
X3X7	0.589	0.173	0.324	0.895	0.381	0.473	0.857	0.606	0.921
	X3	X2	X6	X7	X2X6	X2X3	X2X7	X3X6	X7X6

TABLE 9.6(d)
MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED

TERM THAT WAS NOT DROPPED	MARGINAL TO
X2	X2.X19
X3	X3.X4
X14	X14.X19
X19	X14.X19

TERM THAT WAS NOT ADDED	MARGINAL TO AND NOT IN MODEL
X14.X4	X4
X4.X19	X4

*** Residual mean deviances ***

4.514	Adding	X6.X4
4.541	Adding	X7.X4
4.542	Adding	X2.X14
4.548	No change	
4.551	Adding	X6.X19
4.555	Adding	X6.X14
4.557	Adding	X7.X19
4.559	Adding	X7.X14
4.559	Adding	X3.X14
4.560	Adding	X4
4.561	Adding	X2.X4
4.595	Dropping	X6
4.615	Dropping	X2.X19
4.640	Dropping	X3.X4
4.649	Dropping	X3.X19
4.709	Dropping	X14.X19
5.000	Dropping	X7

Fitted terms: Constant + X2 + X6 + X3 + X7 + X14 + X19
+ X3.X4 + X2.X19 + X3.X19 + X14.X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	10	643.	64.277
Residual	337	1533.	4.548
Total	347	2175.	6.269
Change	0	0.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5966	0.0575	10.38
X2	-0.005148	0.000968	-5.32
X6	-0.03404	0.00755	-4.51
X3	0.03279	0.00404	8.12
X7	-0.005632	0.000448	-12.57
X14 2.00	0.0210	0.0481	0.44
X19 2.00	0.8631	0.0988	8.74
X3.X4 2.00	-0.01650	0.00280	-5.89
X2.X19 2.00	0.00811	0.00156	5.19
X3.X19 2.00	-0.02670	0.00432	-6.18
X14 2.00 .X19 2.00	-0.5741	0.0750	-7.66

* MESSAGE: s.e.s are based on dispersion parameter with value 1

9.9 MODEL SELECTION - THEORETICAL MODEL D

9.9.1 MAIN EFFECTS VARIABLES

The model is closely related to model C but the productive time is classified into detail operation. The first model selection of all the variables in model D is as shown in Appendix F.3. There were 10 variables for model D but in model checking this is increased to 11 variables because variable x12b and x12a do not show a high correlation as in model C. Initial fitting of the data, give a mean residual deviance of 4.945 for model D. After the selection process this deviance is increased to 4.917, an increase of 0.028 of the deviance. 7 variables have been selected as significant from the 11 variables, and the selection process has shown that a parsimonous model of 7 only variables is needed to describe the pattern in the data from the 11 variables. The fit of the model has been increased slightly indicating a better fit with only 7 variables. In comparison to the residual deviance of the null model, the fit of the model with 7 variables can be said to have not explained about 78 percent of the variation in the residuals calculated in the same way as in Model A. This show a poor fit of the model. When comparing with model C, the unexplained percentage is lower eventhough there were only 2 significant variables in model C.

TABLE 9.6(e)
PARSIMONOUS MODEL FOR
THEORETICAL MODEL D

```
***** Regression Analysis *****

  Response variate: NP
    Binomial totals: NT
       Distribution: Binomial
      Link function: Logit
Fitted terms: Constant + X2 + X6 + X3 + X7 + X14 + X4
              + X19 + X2.X19 + X3.X19 + X14.X19
```

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	10	634.	63.380
Residual	337	1542.	4.575
Total	347	2175.	6.269
Change	-10	-634.	63.380

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.8036	0.0733	10.96
X2	-0.005708	0.000987	-5.78
X6	-0.03084	0.00748	-4.13
X3	0.01868	0.00272	6.86
X7	-0.005879	0.000444	-13.25
X14 2.00	0.0276	0.0484	0.57
X4 2.00	-0.2469	0.0481	-5.13
X19 2.00	0.8610	0.0988	8.72
X2.X19 2.00	0.00833	0.00156	5.33
X3.X19 2.00	-0.02650	0.00436	-6.08
X14 2.00 .X19 2.00	-0.5922	0.0747	-7.92

The parameter estimates of the 7 variables is more than 3.00 and thus for the 7 variables the alternative hypothesis for parameter estimation is accepted and are significant in the model. In so doing the remaining 4 variables are not accepted as significant to model D. Table 9.6(a) shows the summary of the results of the modelling for this model. The contribution of the variables is done in the same way as in model A. Table 9.6(b), is the result of the model fitting before the selection of the parsimonous model.

From this it can be concluded that the ranking of the importance of the variable is x19, x7, x4, x6, x3, x14 and x2 which are significant to the model. Again variable x19 contributed to the fit of the model very very significantly. Note that variable x12b and x12a are not selected and thus no new variable is added.

9.9.2 FIRST ORDER INTERACTION -

The first selection reduces the model to 7 variables. and the possibility of all terms to be included in the model is 128. Modelling of only first order interactions will include only 28 terms in the model but Table 9.6(c) indicate that the correlations between all interaction terms from quantitative variables is high and are thus deleted leaving only 22 terms to be tested.

The original fit of the model with 7 variables is 4.917 and the fit with 22 terms is 4.565. The STEP directive was invoke again as in the first selection and only 10 terms are left in the model after the second selection. The fit of the model is now increased to 4.548. However examination of the model (Table 9.d) shows that the terms x3.x4 is in the model, but without the main terms x4. This may result in the problem of interpreting the data. In addition, the t value of x14 is not significant but was not dropped because it is marginal to the term x14.x19. For this reason another selection was done by excluding term x3.x4 in favour of variable x4. Table 9.6(e) shows that the fit becomes less but x4 is significant giving mean residual deviance of 4.575, which has less fit but with the same number of terms. For the reason of choosing the main variable first and satisfying the condition of adding interaction terms as over and above the effect of main effects variables, the interaction terms x3.x4 is dropped in favour of x4. Comparing this with the null model, about 72.9 percent of the variation in the data has not been explained, as compared to about 78 percent in the first selection and 72 percent with the model with x3.x4 but without x4. The variable x14 t values is still not siginificant but is not dropped from the selection process because it marginal to interaction term of x14 and x19.

9.9.3 THE OPTIMUM MODEL FOR THEORETICAL MODEL D -

The result of the modelling have shown that the operation productive time is influenced significantly by 7 variables and 3 first order interaction variables. Thus the hypothesis that trade productive time is influenced by 10 variables has been discounted and the alternative hypothesis that 7 of the variables will explain the variation better when the 10 variables are measured and analysed is accepted. The significant variables and their interactions have helped to explain the variation by only about 27 percent of the variation in the data.

The model is now advanced as:-

Dp= a+ x19 -x6 -x2 +x3 -x4 -x7 -x14 +x2x19 -x3x19 -x14x19

Thus operation productive time is function of floor level; interference to continuity of operations; operation continuity, design/quality interruptions, trade type, operation significance and interaction between floor level and trade type; interaction between floor level and continuity of operation; and interaction between floor level and operation significance.

The implication from this finding indicate that the productive time of manpower when anaysed by buidling element is also largely influenced by the differences in where they are working, confirming again the large influence of floor level on productive time. However the influence of floor level is less marked in this model. Although only about 27 percent of the variation can be explained by the variables, more variables are significant than in model C, but design rationalization is not significant to the model, questioning again this variable influence on productive time. No direction of the influence of main variables contradicts with the hypothesis. The interaction terms show that the floor level influence will also depend on factors such as trade type, operations significance and operations continuity.

9.10 MODEL SELECTION - THEORETICAL MODEL E

9.10.1 MAIN EFFECTS VARIABLES -

The model is closely related to model B but the productive time is classified into gangs. The first model selection of all the variables in model E is as shown in Appendix F.5. There were 10 variables for model E. Initial fitting of the data, gave a mean residual deviance of 4.686 for model E. After the selection process this deviance is decreased to 4.706, a decrease of 0.020 of the deviance. From the 10 variables, 6 variables have been selected as significant and the selection process has shown that a parsimonous model of 6 variables only is needed to describe the pattern in the data from the 10 variables. The fit of the model has been decreased slightly indicating a lesser fit with only 6 variables. In comparison to the residual deviance of the null model, the fit of the model with 6 variables can be said to have not explained about 76 percent of the variation in the residuals calculated in the same way as in model A. This shows a poor fit of the model. Comparing with model B, the unexplained percentage is lower eventhough there were only 6 significant variables in model E.

The parameter estimates of the 6 variables is more than 3.00 and thus for the 6 variables the alternative hypothesis for parameter estimation is accepted and is significant in the model. In so doing the remaining 4 variables are not accepted as significant to model E.

TABLE 9.7(a)
THEORETICAL MODEL E
MODEL SELECTION
MAIN EFFECTS - MODEL SELECTED

*** Residual mean deviances ***

4.668	Adding	X4
4.706	No change	
4.715	Adding	X8
4.718	Adding	X1
4.721	Adding	X5C
4.858	Dropping	X19
4.865	Dropping	X7
4.934	Dropping	X11
4.952	Dropping	X15
5.003	Dropping	X13
5.046	Dropping	X14

VARIABLES DROPPED X5C, X1, X8, X4,

***** Regression Analysis *****

Response variate: NP
Binomial totals: NT
Distribution: Binomial
Link function: Logit
Fitted terms: Constant, X19, X14, X13, X7, X15, X11

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	469.	78.201
Residual	318	1497.	4.706
Total	324	1966.	6.067
Change	0	0.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6162	0.0527	11.68
X19 2.00	0.2906	0.0399	7.29
X14 2.00	-0.4340	0.0409	-10.61
X13	0.008895	0.000899	9.90
X7	-0.004022	0.000542	-7.42
X15	-0.01918	0.00212	-9.05
X11	0.02654	0.00304	8.73

* MESSAGE: s.e.s are based on dispersion parameter with value 1

TABLE 9.7(B)

CONTRIBUTION OF THE SIGNIFICANT MAIN EFFECT VARIABLES TO MODEL E

VAR DROPPED	MEAN RES. DEVIANCE	% UNEXPLAINED RES WITHOUT THE VAR	RANK
X19	4.858	80.1	6
X7	4.865	80.2	5
X11	4.934	81.3	4
X15	4.952	81.6	3
X13	5.003	82.5	2
X14	5.046	83.2	1

TABLE 9.7(c)
CORRELATIONS OF QUANTITATIVE INTERACTION TERMS

	X13	X7	X15	X11	X15X11	X15X7	X15X13	X7X11	X13X11
X13	1.000								
X7	0.423	1.000							
X15	0.500	0.542	1.000						
X11	-0.140	0.107	0.507	1.000					
X15X11	0.121	0.247	0.751	0.825	1.000				
X15X7	0.484	0.792	0.764	0.162	0.407	1.000			
X15X13	0.684	0.590	0.846	0.108	0.403	0.853	1.000		
X7X11	0.192	0.595	0.581	0.536	0.677	0.606	0.424	1.000	1.000
X13X11	0.365	0.378	0.750	0.600	0.814	0.542	0.621	0.734	
X7X13	0.556	0.854	0.577	-0.011	0.173	0.863	0.738	0.386	0.354

TABLE 9.7(d) MODEL SELECTION -SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED MODEL SELECTED

TERM THAT WAS NOT DROPPED	MARGINAL TO
X13	X13.X14
X15	X15.X14
X14	X14.X19
X19	X14.X19

TERM THAT WAS NOT ADDED	MARGINAL TO AND NOT IN THE MODEL
X13.X14.X19	X13.X19
X7.X14.X19	X7.X14
X15.X14.X19	X15.X19
X11.X14.X19	X11.X14

*** Residual mean deviances ***

4.561	Adding	X15.X19
4.569	No change	
4.574	Adding	X7.X14
4.577	Adding	X13.X19
4.582	Adding	X11.X19
4.582	Adding	X7.X19
4.583	Adding	X11.X14
4.644	Dropping	X7
4.667	Dropping	X14.X19
4.681	Dropping	X15.X14
4.682	Dropping	X13.X14
4.836	Dropping	X11

VARIABLES DROPPED X11.X14, X7.X19, X11.X19, X13.X19, X7.X14, X15.X19

Fitted terms: Constant + X13 + X7 + X15 + X11 + X14 + X19 + X13.X14 + X15.X14 + X14.X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	9	527.	58.517
Residual	315	1439.	4.569
Total	324	1966.	6.067
Change	0	0.	*

	estimate	s.e.	t
Constant	0.5697	0.0757	7.53
X13	0.00186	0.00138	1.34
X7	-0.003033	0.000568	-5.34
X15	-0.00408	0.00322	-1.27
X11	0.03100	0.00332	9.35
X14 2.00	-0.3736	0.0870	-4.29
X19 2.00	0.5985	0.0628	9.54
X13.X14 2.00	0.01070	0.00168	6.36
X15.X14 2.00	-0.02509	0.00395	-6.35
X14 2.00 .X19 2.00	-0.4827	0.0809	-5.97

* MESSAGE: s.e.s are based on dispersion parameter with value 1

Table 9.7(a) summarized the results of the modelling for this model. The contribution of the variables is examined in the same way as in model A. Table 9.7(b), is the result of the model fitting before the selection of the parsimonious model.

From this it can be concluded that the ranking of the importance of the variable is x14, x13, x15, x11, x7, x19 and x2 which are significant to the model. The contribution of the 6 variables is however mostly the same, and variable x19 contributed less to the fit of the model as compared to other model.

9.10.2 **FIRST ORDER INTERACTION -**

The first selection reduces the model to 6 variables. and the possibility of all terms to be included in the model is 64. Modelling of only first order interaction will include only 21 terms but Table 9.6(c) shows high correlation between qunatitative interaction terms as found in other theoretical models. Thus only 15 terms will be tested.

The original fit of the model with 6 variables is 4.706 and the fit with 15 terms is 4.600. The STEP directive was invoke again as in the first selection and only 9 terms are left in the model after the second selection. The fit of the model is now increased to 4.569. Comparing this with the null model, about 75 percent of the variation in the data has not been explained, as compared to about 76 percent in the first selection. The t values of variables x13 and x15 is not siginificant but is not dropped from the selection process because they are marginal to their respectives interaction term. No main effects variable has been dropped from the final selection of the model. Table 9.5(d) summarizes the results of the fitting.

9.10.3 OPTMUM MODEL FOR THEORETICAL MODEL E -

The result of the modelling has shown that the operation productive time is influenced significantly by 6 variables and 3 first order interaction variables. Thus the hypothesis that gang productive time is influenced by 10 variables has been discounted and the alternative hypothesis that 6 of the variables will explain the variation as good as when the 10 variables are measured and analysed is accepted. The significant variables and their interactions have helped to explain the variation by only about 25 percent of the variation in the data.

The model is now advanced as:-

$$Ep= a+ x13 -x7 +x15 +x19 -x14 +x11 +x13x14 -x15x14 -x14x19$$

Thus gang productive time is a function of floor level; trade significance; design/quality interruptions; trade duration; trade type task interdependence of trade; interaction between floor level and trade type; interaction between trade significance and trade type; interaction between trade duration and trade type; and interaction between trade type and floor level.

The implication from this finding indicates that the productive time of manpower when analysed by gang is also largely influenced by variables in manpower subsystem and the influence of floor level is less marked in this model. Although only about 25 percent of the variation can be explained by the variables, more variables are significant than in model B. The Variable x11 direction of influence contradicts with the hypothesis.

The interaction effects of trade significance (x13) and trade under control of main contractor (x14) is positive, which was not significant in model B. The positive influence mean that those trades under the control of the main contractor and are significant will be influencing productive time positively. The interaction between trade duration (x15) and trade under the control of main contractor (x14) is however negative, indicating that the longer the gang is employed coupled with the fact that they are under the control of main contractor will be influencing the productive time positively. The infleunce of trade type under the control of the main contractor (x14) and working at upper floor (x19) is negative and is the same as in model B.

CHAPTER TEN

CHAPTER TEN

10 DISCUSSION

10.1 INTRODUCTION

The objective of establishing the more influential variables that cause the inexplicable variations in productive time achievement have been achieved through the modelling technique used during the analysis. Discussion in this chapter will draw attention to the interpretation on the result of the modelling and the evaluation of the methodological approach used.

10.2 NOTES ON THE INTERPRETATIONS

The following notes should be useful in the interpretations of the modelling:-

i. The modelling is based on multiple regression methodology which produce the best sets of significant variables that influence the variations in productive time. The significant variables in each productive time attribute are thus modelled relative to all other variables taken together. The testing of a particular individual variable by itself is not done because it will not approximate and isolate the influence of the variable in relation to other variables.

ii. The empricial findings are specific to the observed manpower productive time on the site under study. However most of the problems that can arise within a particular site are generally applicable to other sites. The variables taken into account in this study have been hypothesized based on this presumption. The major difference will be on the magnitude of influence of a particular factor on other sites and thus insignificant variables in this study may be significant on other sites depending on variation in the data.

iii. From time to time random factors arose during the period of the study and these problems are usually unique to a particular site. These problems include strikes, labour dissatisfaction and accidents. These types of problems have not been analysed as they have not been considered a priori. Some unexplained variation can thus be attributed specifically to the problems experienced on the site studied.

10.3 PRODUCTIVE TIME MODELS

The modelling analysed the influence of factors on the attributes of productive time and thus wide ranging results are obtained. Table 10.1 summarizes the results which in general terms showed wide ranging and interesting implications.

The modelling of each attributes of productive time have explained 25 to 65 percent of the variation in the data. The weekly, element and trade productive time models, explained about half of the variation in their data respectively, whilst the gangs and operations productive time models have explained only about a quarter of the variation in their data respectively. This must not be seen as insignificant as it is not uncommon for research findings to indicate roughly the same variation that can be explained (362). The general indication therefore suggest that the modelling of factors influencing productive time with larger classifications attributes will be more successful. This can give rise to two implications:-

i. Construction work at operation and gang level are widely varied. Despite modelling with many variables, only a quarter of the variation can be explained. Essentially, this means that the unexplained variation can be attributed to unmeasured variables, especially from the motivational sub-system variables or the unique problems mentioned above. It can also mean that considerable proportion of the variation is due to the differences between individual gangs or operations, despite the effort made to measure the influence through variables task type and trade type (x14). However these are relatively broad measures and more specific measures need to be designed. This study supports the general hypothesis that work at gang and operations levels are still subjected to large variation despite the modelling of many variables.

TABLE 10.1

RESULTS OF MODELLING

GENERAL COMPARISONS BETWEEN MODELS

MOD.	MODEL SELECTION 1				MODEL SELECTION 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	10	5	54	53	9	6	58	56
B	7	4	58	58	9	5	66	65
C	11	2	43	43	2	2	43	43
D	10	7	21	22	22	10	27	27
E	10	6	23	22	15	9	24	25

Note:

MOD. = model.

1. = Number of variables tested in initial modelling.

2. = Number of variables in initial optimum model.

3. = Percentage of variation explained by 1.

4. = Ditto by 2.

5. = Number of variables tested in second stage modelling.

6. = Number of variables in optimum model.

7. = Percentage of variation explained by 5.

8. = Ditto by 6.

TABLE 10.2

SUMMARY OF VARIABLES SIGNIFICANT TO ALL MODELS

MAIN VARIABLES	(HYP. INLF)	A	B	C	D	E	(S/N)
X1	-	+					N
X2	+				-		N
X3	+				+		S
X4	-				-		S
X5B	+	+					S
X6	-				-		S
X7	-				-	-	S
X13	+					+	S
X10	+			-			N
X11	-					+	N
X12B	-	-					S
X14	-		-		-	-	S
X15	+					+	S
X18	-	-	-				S
X19	+	+	+	+	+	+	S
FIRST ORDER INTERACTION							
X5BX19		-					
X14X19			-		-	-	
X18X14			+				
X2X19					+		
X3X19					-		
X14X19					-		
X13X14						+	
X15X14						-	

NOTE:
HYP. INFL = HYPOTHESIZED INFLUENCE
S = SUPPORTED
N = NOT SUPPORTED

ii. Variation in trade, element and weekly productive time are therefore less varied. Thus variation at trade level as compared to gang level is more easily explained and so is variation at element level as compared to operation level. There is therefore evidence to suggest that variation between productive time in trades and element are less prominent than the variation in gangs and operations after the factors have been modelled to the data.

The number and types of significant variables differed in each attribute of productive time. This is because of the different nature of the attributes and consequently different sets factors which influence each attribute. In addition a few variables have not been included because the variables cannot be transformed from the database. The indication from this is that each of these attributes needs to be monitored separately and the overall influence of factors on productive time can be deduced only by taking into account the attributes. Table 10.2 summarizes the significant variables modelled to each productive time model and is referred to in the discussions below.

10.3.1 WEEKLY PRODUCTIVE TIME -

The modelling produced 5 significant main variables with 1 first order interaction. The findings indicate that management team, task variabilities, trade variabilities, weather and floor level will be the significant factors to consider in periodic monitoring of productive time.

The overall influence of task variability found in this study provides an indication that an increase in the number of tasks can subsequently increase productive time. The positive hypothesized direction of influence of task variabilities is thus not supported by the data. This means operatives are largely occupied as a consequence of an increase in the number of operations. Thus the probability of higher unproductive time increases when less operations are executed. The execution of a larger number of operations within the production constraints require efficient management in the planning and scheduling of tasks. In addition, during monitoring, quick redeployment of operatives from hold up tasks can help to achieve higher level of productive time.

This research still supports the theory that the amount of daily working time and its effect on performance is crucial (363). But, operatives' time can still be effectively utilized within the constraints imposed by allowable rest period, pause and relaxation allowances to take into account human limitations.

An increase in management team presence at the work place will result in an increase in weekly productive time as shown by the magnitude of influence. This finding therefore supports the theory of essential supervision on-site, although the total management team time observed at the work place is used as a measure and not the total time of supervision.

Work at higher floor levels was found to have higher productive time than work at ground level and the finding is consistent in all models tested. The norm of assuming that work at higher level will reduce actual productivity seems to be contradicted. However, this may be due to several reasons which were noted during on-site observations:-

i. A considerable reduction in productive time proportion at ground level is due to preparatory undertaken work which is not productive.

ii. External work operations are classified in the ground floor section and most of these operations are also usually unproductive.

iii. It was constantly observed, that when operatives were temporarily idle, they will usually be at the ground level.

iv. An operative will still be coded as working at ground level, even when he is preparing materials for production at the upper level.

The three reasons are attributed to the sampling methodology, the classification system used and the nature of interruptions to work. Thus the influence of the floor should not be regarded as contradicting the general hypothesis for estimating productivity of operation above ground level. This finding is however significant because it clearly points to the need for efficient site planning and increasing management presence at the ground level. Efficient site planning will assist in reducing travelling time and reducing the need to prepare materials far from the work place. Increasing management presence at ground level may lead to efficient production.

Trade variability significantly and negatively influences weekly productive time. Which means that an increase in the number of trade types employed can consequently decrease weekly productive time. Thus periodic monitoring should take into account the influence of the number of trade types especially trades that are mainly utilized for a particular week.

Bad weather negatively influences weekly productive time. Although weather conditions are not within the control of management, efforts must be made to ensure continuous working. When it becomes apparent that this will not be possible on certain tasks, redeployment to another tasks is necessary. However, because of specialization, resource availability and time constraints, redeployment will not always be possible. The random but persistent influence of bad weather has resulted in a proportionate and detrimental effect on weekly productive time. Management for this project should have been able to forecast the likely impact of bad weather upon the progress of work especially for task that cannot be properly protected. It was observed that perhaps an earlier starting date could have reduce the effect as the influence was more marked during the first winter season when the building has not been fully enclosed.

The significant interaction effect of floor and management team for this model shows that both variables depend on each other to influence productive time.

The variables that were found to be insignificant and thus not contributing to the fit of the model are the trade type, design/quality interruption, new trade interruptions seasonal influence and weekly weather variation. Of these variables; trade type and seasonal influence have significant t values before they were dropped from the model, but the contribution of these variables to the fit of the model is not significant. However it is suggested that apart from weekly weather variation, these variables must still be tested on other sites because of the probability that the influence of these variables on other sites may be different. Variables weekly weather variation should be measured as the daily or weekly temperature variation which means that the temperature variation should be measured during the study in place of the subjective measure used. In this way the influence of temperature variation can be examined.

10.3.2 TRADE PRODUCTIVE TIME

Trade productive time has been found to be a function of trade type, bad weather, floor location and 2 first order interactions. Two of these variables have also been significantly modelled in weekly productive time; the bad weather and floor level influence.

Some writers have suggested that productive time achievement does not reflect the efficiency of manpower, but the significant influence of trade type on trade productive time contradicts this suggestion. Further evidence to contradict the suggestion can be found in the modelling of gang productive time. The trade type classification used in this research is the classification of trade type within or outside the control of the main contractor. It has been found that trade within the control of the main contractor has lower productive time than the trades outside the control of the main contractor. In particular these trades are the bricklayer, carpenter, general labourer and plumber. This is in agreement with the hypothesized influence. The implication from this finding suggest two possibilities: That either the main contractor has not been controlling its own manpower effectively or that the type of task undertaken by trade within the control of main contractor are largely unproductive. In either case there is a tendency for trade within the control of main contractor to achieve lower productive time and steps should be taken to minimize their unproductive time.

Floor level and bad weather significantly influence trade productive time. The same explanation as in weekly productive time model applies to the above two variables in this model.

The analysis shows that trade within the control of the main contractor at the upper level have more productive productive time than their counterparts at ground level. This confirms the above suggestion that the type of task undertaken by trades within the control of the main contractor are largely unproductive. This is because most preparatory work is done at ground level resulting in a lower productive time of trades within the control of the main contractor at ground level.

The analysis also shows that the influence of bad weather on productive time is dependent upon the trade type indicated by the significant interaction between variables x18 and x14. The result showed that the trade types within the control of the main contractor are less likely to be affected by the weather relative to the trades not within the control of the main contractor. This may suggest that redeployment during bad weather of trades not within the control of the main contractore may be more difficult to undertake.

The variables found to be insignificant in this model are the design/quality interruption, task variability, trade duration, trade significance and interruption to trade employment. Design/quality interruption tested in weekly productive time model was also found to be insignificant. Task variablity which was also tested in weekly productive time model is also expected to show significant influence on trade productive time. An examination of the way this variable was dropped (Appendix

F.2) shows that its t-value is singnificant as it is greater than 6 but was dropped as when it competed with other more significant variables which can fit the model better.

10.3.3 **ELEMENT PRODUCTIVE TIME -**

Floor level and design rationalization were modelled as being significant to element productive time. These two factors were significant out of the 11 variables tested and no interaction effect is significant to the model.

Element duration, trade type, interference to the continuity of element have significant t-values before they were dropped from the model but do not help to explain the fit better as compared with the two significant variables. Design/quality interruption is not significant as in weekly and trade models. While management team, trade variability and operation variability are not significant as compared to weekly model. Task variability was also not significant in trade productive model. Trade type has been found to be a function of trade productive time and it is expected, therefore that element productive time is also a function of element type. The finding does not however support this proposition.

The floor level is still the most significant variable and while design rationalization is significant to this model, it is not significant in operation productive time model. Design rationalization is an aspect of buildability concept forwarded to be a factor which can increase productivity. The hypothesis that element with design rationalization will have higher productive time is not supported by the finding.

However the measure used is very subjective. The measure is the difference between the mean productive time of elements with and without rationalization. The problem in designing a quantitative scaling for the measure of design rationalization element or task is thus highlighted. Good quality data is thus paramount in inferring that buildability factors are not significant to productive time achievement and productivity.

Nevertheless, the lower productive time in element with design rationalization may be the result of the problem in transforming the rationalized design elements. The problem of fit for fabricated components, especially with wall cladding, resulted in an increase in preparation work because the component fit has not been considered in advance. This leads to discontinuity in work. The steel frame for this building was built alongside a lean-to office accommodation with traditional brickwork facade. Whilst both design are rationalized, the progress of work for the steel frame was delayed due to the slow production on the brickwork. The nature of different design components also contributed to the problem. Thus rationalization must take into account the problem of having two different rationalized design when there is a probability that the speed of erection of one is faster than the other. If the problem had been considered during the design stage, the delay reflected from lower productive time in rationalized design elements may be reduced. Rationalized design can still ease production provided the difficulty of production is considered, to induce easier building production.

10.3.4 **OPERATION PRODUCTIVE TIME -**

The variables which are not significant on the element productive time model are however significant in operation productive time model. Design rationalization has been dropped, and this can be attributed to the classification which refers to element with design rationalization instead of operation with design rationalization. The former was used for this model because of the problem of classification. Operation productive time is thus a function of seven variables and four first order interactions.

Variables found to be insignificant in both element and operation productive models are the management team influence and trade variability. This implies that at both element and operation level, the variability in trade type and management prsence are not essential in the achievement of higher productive time. Management and trade variabilities are necessary in monitoring the achievement of productive time periodically. For actual production however, factors within the planning, ad hoc decision, the manpower and site sub-systems are more important.

Design/quality interruptions is negatively significant at operation level. This emphasized the need for better coordination and planning of operation, and prior consideration during design on the problem of production to increase productive time. Task type was found to be significant and the modelling indicate that element of superstructure and services has lower productive time than element of substructure, finishes and external work. This invariably means that production for superstructure and services are more difficult.

Task duration will influence productive time positively, while an increase in the interference to the continuity of task will reduce the operation productive time.

The hypothesized positive direction of influence of operation significance was not supported by the data. The influence of operations significance is negative indicating that operations which is significant will have a lower proportion of productive time.

Thus the implication must be that an operation with higher significance and longer duration must be monitored more closely. The assumption in Section 6.4.1 that higher significant operations that are critical to the progress of work need to be monitored is thus strengthened.

In addition, the significance of interaction between trade type and floor level on productive time is again highlighted supporting the finding in the trade productive time model. It was also found that significant operations at floor level above ground are more productive. Further, an increase in operation duration at floor above ground will lead to lower productive time. All of these interactions point to the work at floors above ground being dependent on the significance of the work, the duration and the trade types within the control of the main contractor to reduce variations in productive time.

10.3.5 **GANG PRODUCTIVE TIME -**

Theoretically, the same factors influencing trade productive time should also influence gang productive time. The modelling however indicates otherwise. One of the reasons is the different sets of factors modelled for both models. The fit for gang productive time is less than the trade productive time model but more factors are needed to explain the variation in data. Six variables and three first order intreactions are significant to the model.

Trade significance, design/quality interruptions, trade duration, trade type, task interdependence of trade and floor level are the significant variables that contributed to the best fit of the model. The variables are from the manpower, the site and the ad hoc decision sub-systems, confirming the hypothesis that gang productive time is also a function of its own variables. It also indicates that good and effective ad hoc decision need to be made from time to time so that productive time can be subjected to less variation.

Design/quality interruption is significant and in agreement with its significance, in the operation productive time model. The same argument presented therein therefore applies. The trade significance and the trade duration were found not significant in the trade productive time model but is significant in this model.

The hypothesized influence, that gang task interdependence, will influence productive time negatively was not supported by the data. The modelling shows that an increase in dependence on the other gangs will subsequently increase gang productive time. It is suspected that the measurement of the variables may have contributed to the contradicting finding. This is because the variable is measured by the total number of times they are coded together in an operation. Since the data is already in aggregate, it has not actually measured the actual dependencies of gangs during task execution. Thus the direction of influence has shown that the hypothesis is not supported and a better measure has to be devised before the hypothesis can be rejected.

In addition, interaction between floor and trade type is also significant, confirming that this interaction factor should be examined carefully in agreement with earlier findings on the operation and trade model. The type will also depend on its significance and duration to influence productive time.

10.4 THE METHODOLOGICAL APPROACH

This research has adopted a simplistic approach in the measurement of time utilization. Time utilization was measured from observed productive time or activity. This essentially mean that the problem involved in observational validity, when determining what activity is to be classified for each observation is largely overcome. Instead of placing a burden on the observer to classify activitites into at least 16 categories, the observer need only to determine two important activities; the productive or the non-productive activities. The definition of productive activity can be made to suit the need and objective of a particular study. Other activities may be recorded as was done in this research because of the procedure laid down by BRESAAP, but they do not form a significant part in the analysis that have been made. Thus this research utilize the basic concept of activity sampling methodology. However in so doing this research has:-

i. Shown that the causes of time utilization can instead be measured by concentrating the measurement on a specific activity without considering the inactivity or indirect activities and relating the achievement to its postulated causes which can be transformed from a database.

ii. Shown that the productive time utilization can be used to examine attributes of production. Thus monitoring of manpower time utilization can be streamlined by just monitoring productive activity provided that empirical measurement of the causes of the aspect of production are made and related to the main measure.

iii. The variability due to the different nature of tasks, trade or craft time utilization can be modelled to improve the understanding of the causes of the variation in time utilization regardless of the variabilities in the attributes of productive time.

The approach has therefore partially solve the problems of determining the causes of time utilization. The Current state of the art in the analysis of time utilization however, demands that data are statistically reliable. Together with the problems of validity of observation, existing methods thus suffer from lack of application at the firm and project level in monitoring onsite production. The statistical reliability of data demanded by the conditions imposed from statistical analysis and the qualification that has to be made in descriptive analysis of data further restrict the potential use of monitoring time utilization. These problems can be overcome if less emphasis is placed on measuring the multiple activity situation. To summarize, they are:-

i. The burden being placed on researchers to digest, dissiminate and comprehend masses of qualitative data and drawing conclusions which cannot be easily explained empirically.

ii. The problem associated in approximating real life determining which are the relevant and more significant problems casuing the variation in the data.

The better solution was to use multiple regression. The problem associated with statistical reliability of the data is again encountered. As much emphasis has been placed upon the statistical accuracy supported by statistical theory, an unecessary burden is placed on the study because data which does not achieve the desired statistical accuracy will have to be discarded thus creating unnecessary redundancy.

This limitation arises because the multiple regression modelling relies heavily on the normal or near normality in data distribution whereas in real world this condition may not always exist as in the case with activity sampling data. In addition, the development of activity sampling originated from the binomial theorem. The complexity of analysis using the binomial distribution without the use of computerized modelling lead to the adoption of the central limit thoerem to approximate the distribution as if it is normal. When data is large or when comparison are made between full site studies, this assumption is true but further investigation as to why data not conforming to this rule, cannot be used has not been made. Even so, in determining the influential factors within a site the assumption will lead to much redundancy. When the distribution of data is not normal, the majority of parametric tests including ordinary multiple regression cannot be validly used. The emphasis on statistical reliability to ensure normal distributed data must have been the prime constraint in increasing the understanding of what has largely influenced the time utilization during production.

The solution to this has only recently been introduced. A thorough examination of the principles of Generalized Linear Modelling, provided an immediate solution to the problem of analysis. It has considerable potential for future applications. The implication in the adoption of this type of statistical modelling is that, for the first time there will be basically no redundancy in data due to the failure to achieve the desired statistical accuracy and thus the validity problem of the methodology is largely overcome.

The use of actual observation as the unit of measure of productive time and not the actual manhours or the percentage of time expended in productive activity will simplify future undertaking. This is so especially in designing database for the processing of data which mean that the BRESAAP algrotihm in the calculation of the actual manhours may not be necessaary anymore. The randomness of observation must however still be ensured.

10.4.1 PRODUCTION SYSTEM AND PRODUCTIVE TIME ATTRIBUTES -

This research adopted the methodology of applying system thinking, modelling and database to enable the examination of the influence of factors on productive time variation. Thus site production is viewed as a system taking into account resources, output, management, production methods and external factors. In so doing, productive time can thus be modelled from the attributes of trade, gang, task and periodic. The postulation of the relationships are thus based on a partial systems approach. This enhanced the inclusion of the influence of many variables. Theoretical modelling then enables the relationship to be hypothesized. The implications from this are:-

i. An examination of the causes that influence productive time cannot take into account one factor at a time. Even the examination of factors within one subsystem is not valid. The modelling of all possible factors has produced the optimum set of factors influencing a particular model. Again in statistical terms the significant factors cannot be ranked and extreme care must be taken if this is to be done. The factors must be taken as a whole given the information provided by the data. This means that under a given production scenario the influence of measured factors can be empirically seggregated using statistical analysis.

ii. The modelling has not analysed the influence of management, manpower, the site and external sub-systems. This is because the measure of the influence of the subsystem has not been devised.

iii. The examination of productive time must be made from many levels as illustrated in this research. A traditional approach of determining the general level of productive time and concluding that a certain set of factors is significant must be avoided in the light of the findings of this research which has shown empirical evidence of the influence of a larger number of factors using the new approach.

Although perhaps BRESAAP has not been fully exploited before, it has enormous potential that has been employed in this research. The use of the database concept in the development of BRESAAP has perhaps eased the extra work that may need to be carried out, although in retrospect a number of practical limitations were encountered.

The possibility of transforming data which can be conceptualized into factors influencing productive time is a contribution this research has made to the existing body of knowledge. The concept forwarded herein suggest the use of a single source of information medium, the OBSERVER, who does not rely on information from others to collect the data. The negative implication of observational methodology has been largely reduced by ensuring that the observer only makes decision on the observable attributes at the point of input of raw data and does not try to make judgement on its causes at this point. In this way further implications can be presented.

i. The validity of the observer's judgement is enhanced when only two activities are required to be snapped. The frequent criticism of biasedness is thus reduced.

ii. The observer record three other attributes, 'WHO', 'WHERE' and 'WHAT'. The determination of the 'WHO' will be difficult when he is not familiar with the operatives, but only if he is interested in each individual productive time. The aspects of production and location, need an observer who is generally familiar but not an expert in all aspects of production. Even remembering the exact location of operative working may not be necessary if only large areas of work are to be examined. These arguments thus emphasize the reduced role and burden of the observer which could only enhance the observational validity.

iii. Nevertheless information can be transformed into variables and unlike other methodology which demand correct response from respondents (FDS) or demanding attribution of causes of influence at observation round (MDPM and the like) or the attribution into causes from the nature of activity (MRC), this concept need only a simple observation at the work place. The validity of the variables transformed can be enhanced by considering several points:-

a. The recoding of attributes and not the causes by a better classification system and data structure relationship so that further variables may be included and existing variables can be further tested.

b. The definition of the variables

c. The way it can be transformed.

d. The automatic transformation to reduce the likelihood of clerical error by effectively designing a database so that retrieval can easily be made through the development of the algorithm of the data base.

It is thus clear from this that the observational methodology used in this research only demands a simple set of rules to be followed:-

i. Determine the definition of productive and unproductive activity.

ii. Capture the sample.

iii. Understand the task classification.

iv. Understand the workplace classification.

CHAPTER ELEVEN

CHAPTER ELEVEN

11 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

11.1 SUMMARY OF FINDINGS

Considerable variations in productive time expenditure were found for all attributes of productive time examined. An average of 41 percent for productive time expenditure for the whole site was also recorded. The considerable variations and low average productive time, confirmed the hypothesis of normally low productive time expenditure and wide variations in on-site production.

The phenomenon of high variation and low productive time achievement during on-site production investigated in this research has produced substantial evidence that suggests many varied factors as causes. Evidence presented herein suggests that at least a quarter of the variation can be explained. The extent of the success may have been partly due to the omission of some variables, and thus that the variability may have been further reduced if BRESAAP had not limited the choice of variables to be measured.

Fifteen factors ranging from aspects of management of construction, management of design, through manpower, to external and site factors significantly influence the attributes of productive time. Most of the factors derived from previous related research have been further validated, but a few specific findings were contradicted.

Of the variables postulated to have significant influences on the variations in the attributes of productive time, the analyses have yielded the following variables which were found to be statistically significant within the data obtained in this study:-

i. **Task variability positively influences weekly productive time;**

ii. **Task significance negatively influences operation productive time;**

iii. **Task duration positively influences operation productive time;**

iv. **Task interruption negatively influences operation productive time;**

v. **Operations in superstructure and services elements, have, on average lower productive time than operations in substructure, external work and finishes;**

vi. **Management team presence at the work place positively influences weekly productive time;**

vii. **The negative influence of design/quality interruptions was found on gang and operations productive time;**

viii. **Rationalized design elements have on average lower productive time than unrationalized design elements;**

ix. Task interdependence positively influences gang productive time;

x. The trade variability negatively influences weekly productive time;

xi. Trade significance positively influences gang productive time;

xii. Productive time of trades within the control of main contractor is on average lower than trades outside the control of main contractor;

xiii. Trade duration influences gang productive time positively;

xiv. Bad weather negatively influences weekly and trade productive time;

xv. The productive time of floor level above ground is, on average, higher than that at ground level.

The above variables may thus have some influence on productive time expenditure on construction sites, although the findings as are contrained by several factors, the main one being the restriction imposed by the BRESSAP. The need to develop a new database replacing BRESAAP will be discussed in section 11.6.2, which may help to further validate and/or explore the influence of other measured factors.

11.2 IMPLICATIONS OF FINDINGS

The examinations by means of theoretical and statistical modelling on variations in productive time achievement within the site production process culminated in the above findings. The modelling of productive time attributes will contribute to an empirical explanation of the causes of the variation. The assumed variation in productive time is associated with the nature of construction work and also with other factors. Productivity can be optimized if the negative influences are reduced and the positive variables enhanced.

11.2.1 UNSUPPORTED DIRECTION OF INFLUENCE -

Four hypothesized directions of influence of the variables are unsupported by the data although the variables are statistically significant. The variables are the task variability, task significance, task interdependence of trade and design rationalization.

Elements with rationalized design have lower productive time than elements with unrationalized design. Task variability and task interdependence of trade influence productive time positively while task significance influences productive time negatively.

The hypothesized negative influence of task variability was not supported by the data. On the contrary, a positive influence was derived from the modelling. The findings thus suggest an increase in task variability will increase productive time. This contradictory finding will need further empirical evidence: logically, an increase in task variability would be expected to decrease productive time. The finding, however, supports the notion of the advantages of dividing work into many tasks or operations as emphasized by proponents of buildability.

The negative influence of task significance does not support the hypothesis of its positive influence. In conceptualizing the positive influence it was assumed that significant tasks would be extensively monitored and controlled. The data suggests that an increase in significance of task will result in a lower productive time from such tasks. The finding hence suggests that production monitoring has been carried out for operations regardless of their significance. The monitoring of production tasks thus has therefore not taken into account this criteria. Although the hypothesis is not supported, the need extensively to control and monitor more significant tasks in order to increase their productive time may be emphasized by the finding. The impact on productivity may be remote, but implication of this finding is that productivity of significant task may be low if not extensively monitored.

The significance of design rationalization provides further confirmation of the influence of design on productive time and hence productivity. The finding suggest that rationalized design elements have on average, lower productive time than unrationalized design elements. This finding therefore does not support the positive influence of rationalized design on productivity, which has been construed as a by-product of buildability efforts.

The positive influence of task interdependence, as against the hypothesized negative influence, does not support the notion that dependency on other trade types will slow down the flow of work during production. The discussion in Chapter 10 points to the possibly inaccurate measure used for the variable and thus, notwithstanding the data analysed in this research, the hypothesized negative influence is upheld.

11.2.2 SUPPORTED FINDINGS AND THEIR IMPLICATIONS -

Eleven findings support the hypothesized influence and are statistically significant. These are the task duration, task interruptions, operations type, management team presence, design/quality interruptions, trade variability, trade significance, trade type, trade duration, bad weather and floor level.

An increase in task duration will subsequently increase productive time. One of the factors influencing productivity is the learning curve factor and it is a function of time or duration of tasks. This finding is therefore, in agreement with the known influence of learning curves on productivity, where it is expected to be optimum once the 'learning' problem has been overcome.

Hence tasks with longer durations should, in totality, have a significant influence on productive time and contribute to the process of learning to induce higher productivity.

Increases in task interruptions will decrease productive time. Increasing interruptions to task continuity will also result in an increase in the number of visits. The overall implication will be that an increase in task duration and a decrease in interruption to continuity are of utmost importance to enhance the effect of learning on productivity as well as being significant to productive time.

In general, tasks within the element of superstructure and services inherit production constraints, as implied from the lower productive time found in this group of elements. This finding has not been reported before. The production constraints associated with these elements have not been indentified by the data. A hypothesis can be advanced that, in general, tasks in this group of elements will have on average lower productivity than tasks in other elements. Such a hypothesis will therefore need further confirmation in future research and the production contraints will have to be established in definable terms.

The positive influence of management team presence on the productive time unequivocally confirmed the need to increase the level of supervision to increase productive time. The influence of management has only been explored in its effect through physical presence at the work place, including both supervisory and non-supervisory activities. This finding further reinforces the general recognition of the influence of management on productivity, as found in many studies.

The negative influence of design/quality interruptions on productive time strongly suggests that quality and design should be primarily considered during the formulation of project proposal and design stages. The effect of repeat work on productive time has been used as a measure for the influence of interruption due to design/quality. Although design and quality have been investigated as separate variables, the combination of the two as a single variable is due to the difficulty of distinguishing their influence.

During planning and scheduling the level of quality and allowable design variation should also be confirmed. It should be of paramount importance that the level of repeat work is minimized and when it is apparent that the level of repeat work is increasing, efforts must be made to diagnose the possible source of the problems. The effect of increasing repeat work on the motivation of operatives should also be seen as significant, although not investigated in this research.

Trade variability negatively influences weekly productive time. An increase in the number of trade types employed for on-site production will lead to a decrease in productive time. Trade variability may not be easily reduced and thus an effective and continuous monitoring of site production should be undertaken when the number of trade types employed increases.

Increase in the significance of a task was found to decrease productive time, but the trade significance influences productive time positively. As with task significance, trade significance was measured from the contribution of trade time to the total manhours of the task undertaken.

The findings are not contradictory as each variables attempts to measure a different influence. There is evidence to suggest that productive time of more significant trades will be generally higher. The emphasis must therefore be to monitor the trade type which are less significant, especially the trades that are employed only for a short and specific period of time.

This also suggests that productivity of tasks can be increased if the gang is well balanced, hence reducing the potential impact of insignificant trade or gang on productivity.

Trades within the control of the main contractor on average recorded lower productive time than the trades outside the control of the main contractor. Greater control on the trade within the control of the main contractor is thus essential. This is not withstanding the discussion in chapter 10, which suggests that another reason for lower than average productive time for trades within the control of the main contractor is the type of tasks undertaken which are not always productive. In essence, productivity of tasks which utilize trades within the control of main contractor is expected to be lower.

Trade duration influences productive time positively. An increase in the length of employment for a type of trade will thus result in a subsequent increase in productive time. As with task duration, there is evidence to suggest that familiarity with the nature and requirement of the task, the site layout, the general problems of production on a particular site and the learning curve factor are causes for trade duration to exhibit such influence. This finding therefore emphasizes the need for a longer period of employment for operatives for on-site production. To increase the overall productivity of a task, trades should be employed for a considerable period so that the problems outlined above can be overcome.

Bad weather influences productive time negatively. An increase in the number of hours lost due to bad weather will result in a subsequent decrease in productive time. Many other aspects of weather influence have not been examined. The probability of bad weather influence on production should be taken into account during pre-contract planning not only by the contractor but also by the client's advisors, especially when considering the actual construction period.

Data from the monitoring indicates extensive loss of manhours during winter months when the building has not been enclosed. Starting construction work during spring or early summer may reduce the detrimental effect on the ground and substructure work which are susceptible to bad weather. The building can at least be partially enclosed when winter approaches. This is especially true for medium size projects where the period of enclosure is usually shorter. The effect on productivity of work stoppages due to bad weather on productivity should also be expected to be significant.

The productive time at floor level above ground is on average higher than at the ground level. The variable is significant for all attributes of productive time analysed. The discussions in Chapter 10 have explained the reasons for the differences.

The conclusion drawn from this finding is that extensive control and monitoring must be undertaken at ground level because most unproductive activities related or unrelated to production occur at ground level. The presumption that work higher up will reduce in its productivity still gains no evidence from this research.

11.3 IMPLICATIONS FOR THE MANAGEMENT OF PRODUCTION

There is evidence in the findings of this research to suggest that the productive time of manpower is a function of variables within the planning and scheduling, management, ad hoc decision, the manpower, the site and external sub-systems. Instead of the original 19 factors, 15 factors were found to be significant.

This suggests that although many and varied factors influence productive time and thus productivity, only some factors significantly influence the variations in the data. For managers at the site level, the emphasis must be to be able to diagnose the relevant and significant variables which cause the negative variations. In addition, the positive influence of certain variables suggests that enhancing their contribution could lead to higher productive time.

During planning and scheduling, tasks should be planned so that quick and efficient redeployment of resources to other tasks can be made when unscheduled delay occurs. Tasks should also be planned so that fewer visits are necessary. Tasks which are significant should also be more carefully monitored.

During production monitoring, management must increase the amount of time they spend at the work place in order to causally increase the productive time. If there are indications that the level of repeat work is increasing then coordination of design requirements must be finalized before production so that design requirements are understood by operatives and managers alike. The quality of work desired should also be agreed before production. Trial production on a smaller scale can always help to define the degree of quality required.

Managers must be aware that stoppages will necessitate further visits by gangs, which will reduce productive time hence productivity. Thus, although ad hoc decisions are often necessary to increase production efficiency, decisions which can result in production discontinuity and consequently prolong idleness, should be reduced as far as possible.

In addition, the structure and services elements need to be more extensively monitored in the light of the evidence suggesting that production in these elements has lower than average productive time.

In the management of manpower, more extensive monitoring can be directed at the following groups: trades within the control of the main contractor; trades with shorter duration; and trades with less significance in task production. It is also necessary to reduce the number of trade types employed during the construction period.

In the management of design, designers should be aware of any problems inherent in the design itself. The problem associated with the design transformation and compatibility between design may be more important than the rationalization of design. This means that effective communication of design must be a paramount consideration for designers. Managers must be quick to detect potential problems in design realization and tackle the potential problem before production begins, thereby reducing the amount of possible repeat work.

The protection of work against bad weather must also be of prime concern for managers, while better site planning and monitoring at ground level can also increase productive time.

11.4 CONCLUSION

The time factors in project management have been emphasized from many aspects (356-358). Most contemporary opinion has by and large concentrated on the influence of time on project duration, construction period and delays on site. This is due to the increase in project duration and the contruction period can easily be related to cost. Loss due to lower than average productivity is, however, more difficult to ascertain and quantify. Whilst low productivity can also prolong the construction period hence project duration, low productivity can be a result of low productive time utilized on site production.

Time management from productive time has only won attention recently and particularly in the USA, where its use as a surrogate productivity measure in monitoring onsite production process is increasing. This is because it is somewhat easier to measure productive time as against other measures and produce quantifiable data that can detect potential problems during production. There is evidence from previous studies to suggest that the productive work needs to be narrowly defined to ensure its effectiveness as a surrogate measure.

The measurement of factors influencing other productivity measures is now enhanced by the measurement of factors influencing productive time. This is a logical step towards making productive time measurement more practicable at the site level. Thus current understanding that its measurement can detect problems is thus confirmed.

It is therefore recommended that site management undertake efforts to monitor the expenditure of productive time during production to optimize manpower utilization. The methodology adopted for this research can be further refined for use on a practical basis. The methodology can form part of a comprehensive improvement program where the use of activity sampling has been recommended (359). This is in agreement with Laufer (360), who suggested that, as part of a multiple productivity facets onsite, the process of symptom identification and diagnostic activity should precede the process of pinpointing relevant areas for productivity improvement.

Since it can now be shown that management as well as manpower can influence productive time, the productive time measurement and subsequent analysis of causes can be used as a tool to assess manpower performance. The attribution of responsibility for failure to achieve desired output can be part of a productivity agreement between management and union (361). Uneasiness on the part of manpower during production monitoring of manpower productive time can be reduced if it is known that low productive time or the considerable variations that may be identified will not necessarily be attributed to manpower alone.

11.5 LIMITATIONS OF RESEARCH FINDINGS

The findings of this investigation are by no means so definitive as to provide unchallenged empirical evidence for the causes of productive time utilization. These findings although restricted is valid, thus further research should be more exhaustive in the choice of variables that can be postulated to have significant influences on productive time within the practical limitations of research framework. They do however increase further understanding of the subject area investigated. The validation of the hypothesized influence of variables provides evidence to suggest the causes and can be used as a basis for further investigation in this area. The findings should also serve to increase awareness of the problems associated with on- site production.

Specific limitations to the findings outlined in various parts of the thesis are summarized below:-

i. The modelling of the variables includes only variables that can be acommodated by BRESAAP. The influence of variables not modelled cannot be discounted.

ii. The theoretical model conceptualized for this research is only a partial model.

iii. The influences of the variables have been modelled relative to each attributes.

iv. The influences of the variables does not take into account the opposite direction of influence of productive time on the variables.

v. The modelling has not specifically ranked the importance of the variables. For each attribute of productive time, a set of statistically significant variables is produced as a result of the modelling.

11.6 RECOMMENDATIONS FOR FUTURE RESEARCH

Future work should be directed at two avenues which are seen as essential in further confirming the findings of this research and utilising contemporary advances in the fields of social research, statistical techniques and computer technology.

11.6.1 RESEARCH TO CONFIRM AND INCLUDE FURTHER VARIABLES -

Future research should be directed at the following areas which should further contribute to the understanding on this subject area:-

i. Researching further factors that influenced productive time by including more variables, especially those concerning the manpower motivational sub-system.

ii. Developing more reliable measures of the effect of design rationalization, of the influence of temperature or weather variation on productive time, and of task interdependence.

iii. Developing a mathematical construct, perhaps in the form of simulation modelling, whereby the influence of variables can be reliably estimated. The need is to be able to provide a model which can determine the minimum and maximum value for a variable and the range of its influence to minimize or maximize its effect on productivity.

11.6.2 DATABASE FOR PRODUCTION MONITORING -

There is clearly a need to develop a new database for the measurement, processing, transformation and retrieval of information relating to the expenditure of productive time and the factors that influence it. Existing facilities will not be able to satisfy the need for future research. In addition, the need to monitor production, especially as regards manpower necessitates the use of computerized technology more advanced than the existing capability of BRESAAP. It should reduce manual work, except on the input of raw data into the database and specifying the type of output needed for a particular level of productive time. Further analytical work should then be able to take over from the database, reading and analysing the information required.

The database should be developed to take into account of the following:-

i. The natural relationship between the attributes of productive time.

ii. The natural relationship of the variables influencing each attribute.

iii. The development of a logical data structure to accommodate the above relationship.

iv. The development of an algorithm to process the data, to transform it and to retrieve.

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APPENDICES

A.1 Operatives and management team

Coding

TRADE LIST: OPERATIVE CODE AND NUMBERING

Asphalter	1 - 50
Foreman	51 - 60
Apprentice	61 - 70
Labourer	71 - 100
Bricklayer	101 - 150
Foreman	151 - 160
Apprentice	161 - 170
Labourer	171 - 200
Cptr/Joiner	201 - 250
Foreman	251 - 260
Apprentice	261 - 270
Labourer	271 - 300
Electrician	301 - 350
Foreman	351 - 360
Apprentice	361 - 370
Labourer	371 - 400
Floor Layer.	401 - 450
Foreman	451 - 460
Apprentice	461 - 470
Labourer	471 - 500
Gas Fitter	501 - 550
Foreman	551 - 560
Apprentice	561 - 570
Labourer	571 - 600
Glazier	601 - 650
Foreman	651 - 660
Apprentice	661 - 670
Labourer	671 - 700
Painter	701 - 750
Foreman	751 - 760
Apprentice	761 - 770
Labourer	771 - 800
Scaffolder	801 - 850
Foreman	851 - 860
Apprentice	861 - 870
Labourer	871 - 900
Roofer/Sltng	901 - 950
Foreman	951 - 960
Apprentice	961 - 970
Labourer	971 - 1000

Genl/Lab.	1001 - 1050
Ganger	1051 - 1060
Plant Driver	1061 - 1100
Gardeners Landscapers	1101 - 1150
Wrought-Iron Worker	1151 - 1160
Gas Heating Engineer	1610 - 1650
Foreman	1651 - 1660
Apprentice	1661 - 1670
Labourer	1671 - 1700
Elec Heating Engineer	1701 - 1750
Foreman	1751 - 1760
Apprentice	1761 - 1770
Labourer	1771 - 1800
Plumber	1801 - 1850
Foreman	1851 - 1860
Apprentice	1861 - 1870
Labourer	1871 - 1900
Tiler	1901 - 1950
Foreman	1951 - 1960
Apprentice	1961 - 1970
Labourer	1971 - 2000
Office Staff	
Agent	2001 - 2050
Site Engineer	2051 - 2060
Electricity Board	2501 - 2550
Foreman	2551 - 2560
Apprentice	2561 - 2570
Labourer	2571 - 2600
Gas Board	2601 - 2650
Foreman	2651 - 2660
Apprentice	2661 - 2670
Labourer	2671 - 2700

Water Board	2701 - 2750
Foreman	2751 - 2760
Apprentice	2761 - 2770
Labourer	2771 - 2800
PO/Eng.	2801 - 2900
TV Relay	2901 - 2950
Public Lghtng/ Engineer	3001 - 3050
Ceiling/Ptn.	3051 - 3100
Steel Fixer	3101 - 3110
Plasterer	3111 - 3150
Apprentice	3151 - 3154
Labourer	3155 - 3160

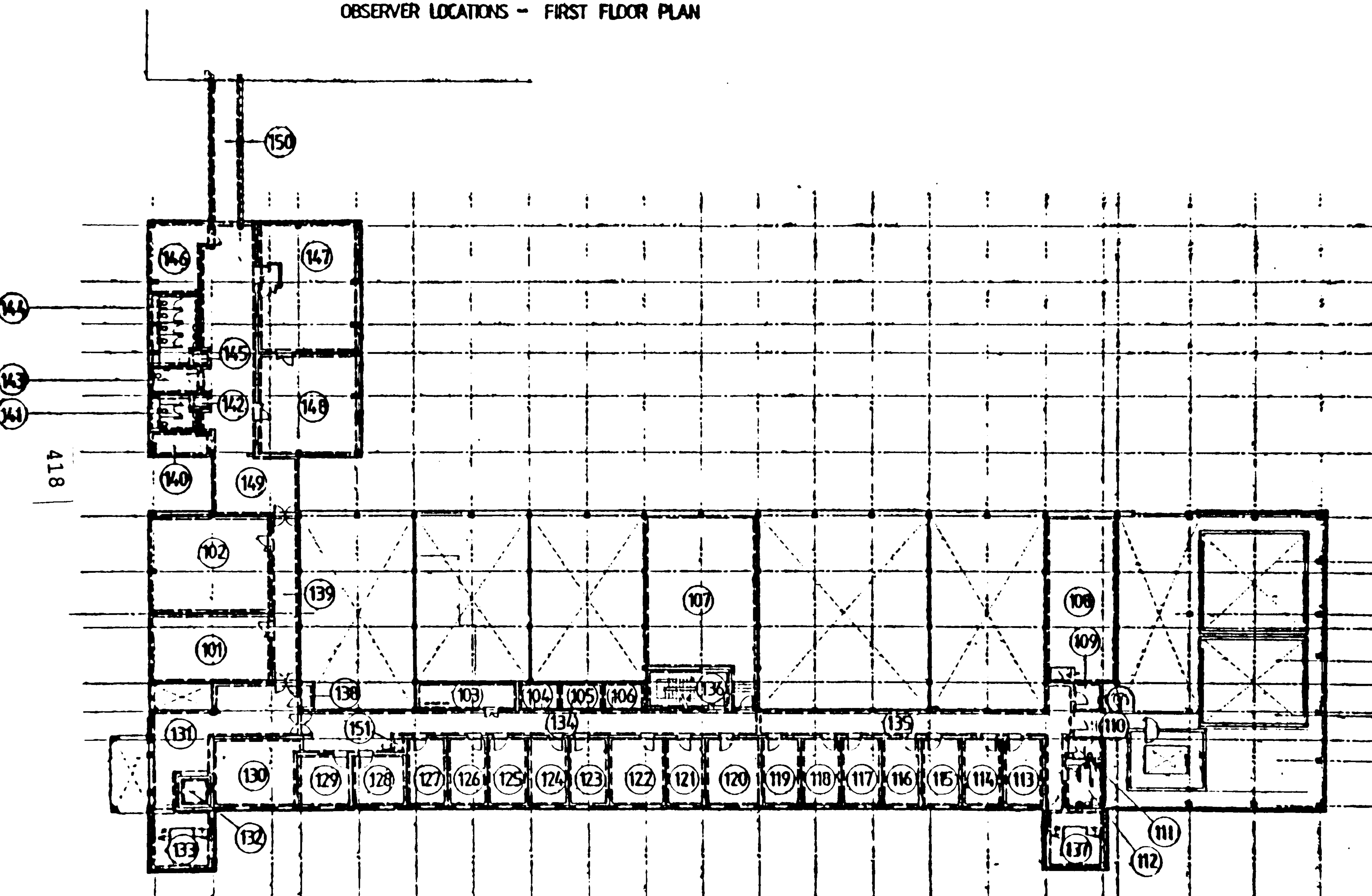
<u>Piling</u>
Foreman 3161 - 3170
Labourer 3171 - 3200

OBSERVER LOCATIONS — PILE LAYOUT

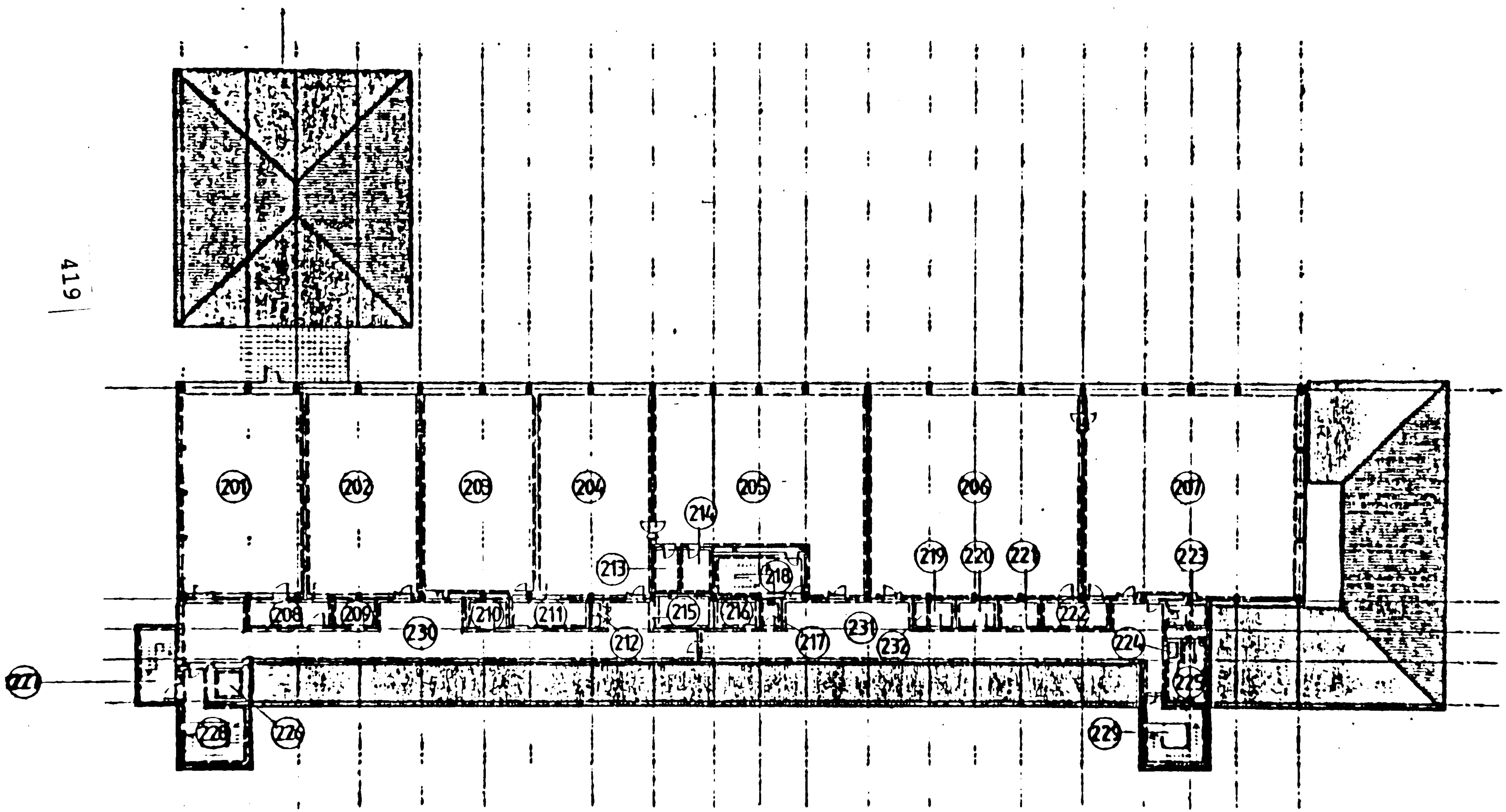
A.2 Workplace coding

OBSERVER LOCATIONS - GROUND FLOOR PLAN

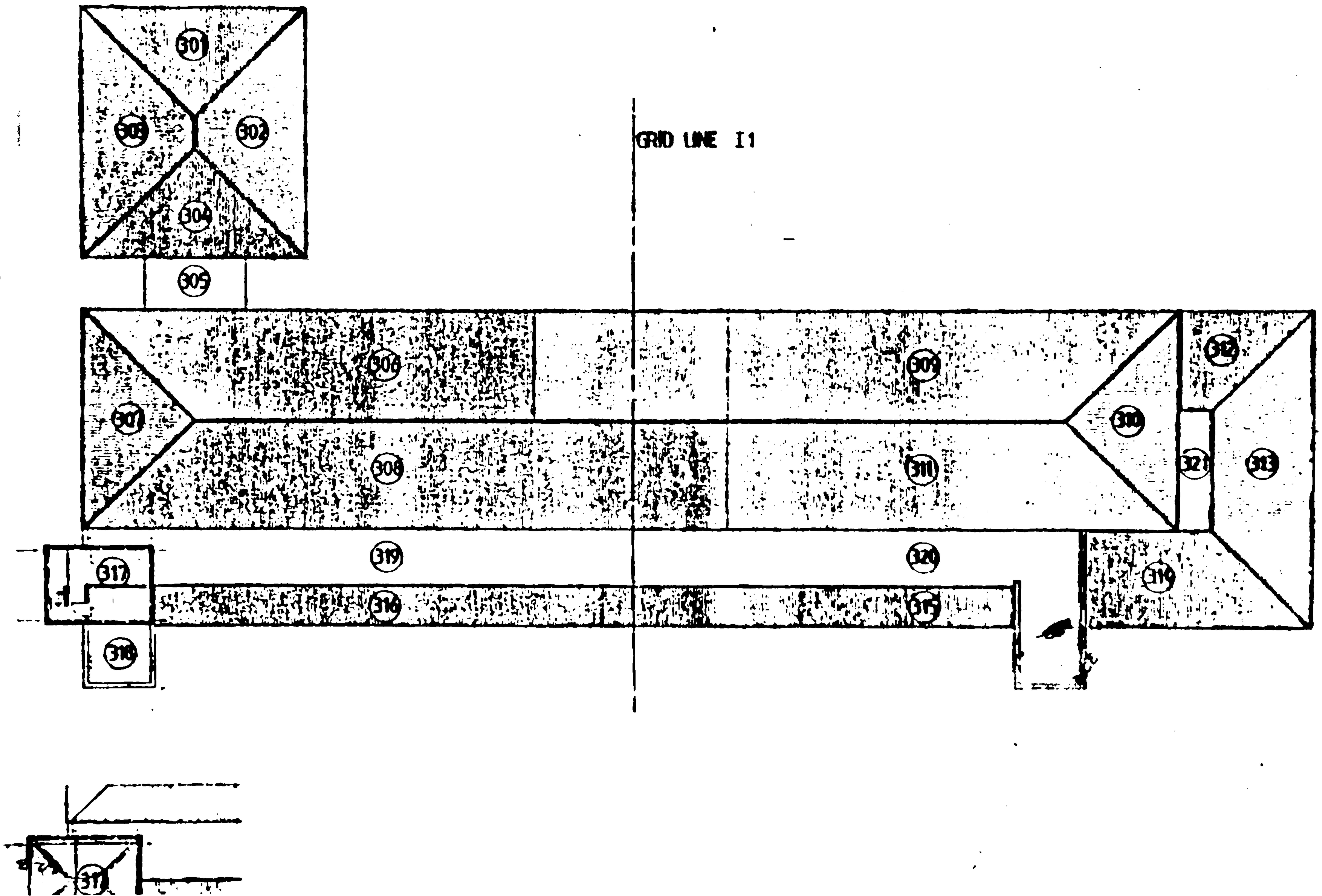
OBSERVER LOCATIONS - FIRST FLOOR PLAN



OBSERVER LOCATIONS - SECOND FLOOR PLAN



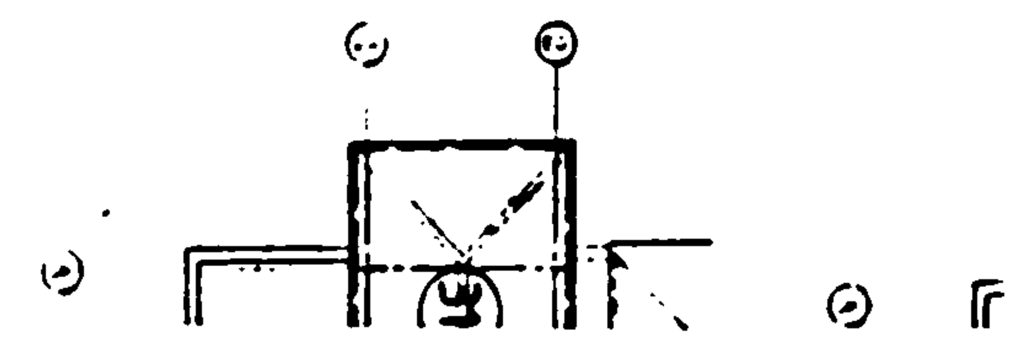
OBSERVER LOCATIONS - ROOF PLAN



A.3 Worktask coding

ELEMENTS AND OPERATIONS LIST

NO.	ELEMENT		OPERATION	
1.	External Works			
		A	Establish Site Compound	
		B	Site Preparation, Setting out and Demolition	
		C	Make up Levels: Hardcore, Compacting, Blinding	
		D	Retaining Walls	
		E	Roads	
		F	Paths	
		G	Landscaping and Planting	
		H	Fencing	
		I	STEPS [illegible] F [illegible]	
		J	OTHER	
2.	Temporary Services			
		A	Water	) Excavation, installing,
		B	Electricity	) and backfilling, i.e. All
		C	Gas	) associated works.
		D	Telephone	)
		E	Site Lighting	)
		F	DRAINAGE [illegible]	
SUBSTRUCTURE				
3.	Drainage			
		A	Setting out, excavation, bottoming	
		B	Drains: Bedding and support, test, protection, backfill and test	
		C	Manholes	
		D	Other	
4.	Oversite Excavation			
		A	Excavating oversite to reduced levels	
		B	Other	
5.	Piling			
		A	Bore	Precast Driven Piles
		B	Reinforcement	
		C	Concrete	
		D	Formwork for pile caps	D
		E	Reinforcement	E
		F	Concrete	F
		G	Remove Formwork	G
		H	Removing Surplus Concrete from piles	
6.	Foundations			
		A	Excavation	
		B	Blinding	
		C	Formwork	
		D	Reinforcement	
		E	Concrete	
		F	Remove formwork	
		G	Backfill to ground beams etc	
		H.	[illegible]	



7. **Ground Floor Slab**

A Hardcore
B Blinding
C Damp proof membrane
D Edge formwork (any type)
E ,Reinforcement
F Concrete
G Finish
H Remove formwork
I Protection of concrete
J Other ,

Sawing steelwork

SUPERSTRUCTURE

8. **Steelwork**

A Columns
B Beams (Horizontal)
C Beams (Sloping - Roof)
D Cladding rails (vertical surfaces - walls)
E Purlins (Roof)
F Other

9. **Brickwork/ Blockwork**

A To cavity walls
B To internal walls
C To columns
D Lintol
E Other

10. **Scaffolding**

A Erecting
B Dismantling
C Moving (mobile types)
D Other

11. **Upper Floor Slabs**

A Precast concrete slabs
B Formwork
C Reinforcement
D Concrete
E Finish
F Remove [illegible]
G Screed
H Other
I [illegible]

I [illegible] Steel
11/2/85

12. **Stairs/Landings**

A Precast stairs
B Formwork
C Reinforcement
D Concrete
E Remove formwork
F Finishing
G Handrails and Balustrades
H Spiral staircase
I Other

13. **Roof Covering and Finish**

A Fixing roof cladding panels (Korrugal Energi Roof System)
B Jointing
C Forming eaves
D Forming ridge
E Forming gables
F Other

14. **Wall Cladding**

A Fixing wall cladding panels (Korrugal Energi Roof System)
B Jointing
C Detail to base of cladding
D Detail to eaves cladding
E Detail to corners cladding
F Detail to opening cladding
G Curtain walling
H Other

15. **Door/Window Details**

A External doors
B External windows
C Internal doors
D Internal windows/screens
E Ironmongery
F Specialised doors: roller shutter rubber doors, etc.
G Other

FINISHES

16. **Floor Finishes**

A Granolithic
B Clay quarry tiles
C Vinyl tiles/sheeting
D Rubber tiles/sheeting
E Carpets
F Other

17. **Wall Finishes**

A Plasterwork
B Ceramic tiles
C Painting
D Other

18. **Ceiling Finishes**

A Plasterwork
B Vermiculite plasterwork
C Suspended ceiling system
D Painting
E Other

F = Gypsum [illegible]

17 E
18 D Painting
14 C Other

19. Glazing

- A Windows
- B Doors
- C Screens
- D Other

20. Joinerwork

- A Architraves/skirting
- B Boxing/ducting to pipes etc
- C Detail to openings windows etc
- D Other

21. Painting/Decorating

- A Doors
- B Windows
- C Architraves/skirtings
- D Other

22. Fixtures/Fittings

- A Sanitory Provisions (sinks, w.c. etc)
- B Cubicles (to w.c.)
- C Kitchen fitments
- D Shelving, mirrors, coat hooks, etc
- E Benches/cupboards
- F Pinboards, etc
- G Other

SERVICES

23. Plumberwork

- A Flashings
- B Rainwater gutters, outlets/downpipes
- C Soil, waste and vent pipes
- D H/C supply pipework, tanks, calorifier and lagging
- E Testing and commissioning
- F Other

24. Electrical

- A Wiring
- B Socket outlets, switches and fittings
- C Meters and Controls
- D Testing and commissioning
- E Other

25. Heating

- A Flow and return pipework
- B Radiators and Heating Units: installation and connection
- C Boiler room plant: boilers and calorifiers installation and connection
- D Testing and commissioning
- E Other

26.	**Ventilation/ Air Condition**		
		A	Ductwork
		B	Extract Units: roof and wall mounted
		C	Boiler room plant: installation and connection and ventilation fans
		D	Testing and commissioning
		E	Other
27.	**Gas**		
		A	Pipework
		B	Meters and controls
		C	Fixings to outlets
		D	Testing and commissioning
		E	Other
28.	**Specialist Services**		
		A	Fire provision
		B	Fire alarms
		C	Security system
		D	Other
29.	**Services Builderwork**		
		A	Holes in Blockwork/Brickwork
		B	Holes in roof deck or finish
		C	Chasing blockwork and sinking outlet boxes
		D	Mastic sealing and cover plates to pipework
		E	Service entry pits
		F	Making good: plasterwork and finishes
		G	Other
30.	**Cleaning/Rectifying Defects**		
		A	Cleaning
		B	Making good defects
		C	Other

OUTBUILDINGS

31.	**Materials Store**		
		A	Excavation
		B	Hardcore, blinding
		C	D.P.M.
		D	Formwork
		E	Reinforcement
		F	Concrete
		G	Remove formwork
		H	Walls
		I	Roof
		J	Doors
		K	Other

A.4 Activities coding

ACTIVITY LIST

Directly Productive

- P1 Making the building grow

Indirectly Productive

- U1 Unloading
- H1 Handling around the site
- H2 Handling from stack to workplace
- SU Supervision
- T1 Setting out and measuring
- T2 Testing HW pipes, drains, etc
- P1 Preparation of materials
- CL Cleaning tools or clearing up
- RT Work repeated
- N Not working while at workplace

Non-Productive

- I Not working while around site
- W Walking
- BK Meal Breaks
- RO Work stopped due to the weather
- A Operative not seen during the round

A.5 Daily Record sheets

GUIDANCE NOTES FOR COMPLETING OBSERVERS DIARY - 1

GENERAL RECORD

1. WEEK NO.: Corresponding to contractors week number.

2. DAY: Day of the week.

3. DATE: Day number, month number and year number.

4. WEATHER: To correspond to the following headings

FINE:	not adversely affecting work on site
COLD:	down to freezing - minor hold up
VERY COLD:	freezing - major hold up
WET:	rain - minor hold up
VERY WET:	rain - major hold up
WINDY:	minor hold up
VERY WINDY:	major hold up
FOG:	minor hold up
VERY FOGGY:	major hold up

RECORD OF MEN AND MATERIALS ON SITE

5. WORKFORCE OBSERVED ON SITE TODAY: Full description of the workforce by trade and status, plus any visitors to the site.

6. PLANT OPERATING ON SITE TODAY: Full list of major items of plant being used with description and number of each type.

7. MATERIALS DELIVERED TO SITE TODAY: Full list of materials delivered giving type of material, quantity, method of delivery and unloading and loaction of storage.

8. NEW OPERATIVES ON SITE TODAY/OPERATIVES LEAVING SITE TODAY: Full list of new operatives on site, stating number, trade and status and whether main contractor or sub-contractors men.

9. NEW PLANT ON SITE TODAY/PLANT OFF SITE TODAY: Full description of new plant on site with description as in 7 above, plus note of plant taken off site.

RECORD OF WORK DONE DURING THE DAY

10. WORK OBSERVED DURING THE DAY: A full description of the days work related to the list of elements, e.g. blockwork - internal partitions. List of all elements worked on during the day and complete "quick check" box.

11. NEW WORK STARTED: A full description of all new work started, i.e. elements not previously recorded. (A in "quick check" box).

12. EXISTING WORK COMPLETED: Description of element or operation completed during the day. (E in "quick check" box).

13. WORK METHOD: Description of the way the workforce is divided up into gangs, the number of gangs plus number and status of men in each gang for the principle element worked on during the day including plant used.

14. An account of the days activities other than recorded above - eg. men laid off for the day due to inclement weather, or working in other areas out of normal sequence of operations, visits by supervisors, problems encountered with unusual methods of working, reports of vandalism, etc.

OTHER ASPECTS

15. EVENING/WEEKEND WORKING: A note that weekend or evening work has taken place plus brief description of work done and trades involved.

16. CODING CHANGES: A note of coding amendments or additions (new operations and

BOX: Complete in accordance with separate guidance notes.

GUIDANCE NOTES FOR COMPLETING OBSERVERS DIARY - 2

ELEMENT "QUICK CHECK" BOX

The right hand columns contains a sequential list of elements against which should be marked the appropriate code shown below, to indicate what work has been done during the day. If no work has taken place on an element which has yet to be started the box should be left blank, or if the element is complete in accordance with the guidance notes below a diagonal line should be drawn through the box.

HEADING	DESCRIPTION
A	NEW ELEMENT started today. No work previously done on this item. (give description under heading 11 - New work started on diary sheet).
B	CONTINUATION of work to an element. No break from the previous days work and no significant break during the day. (enter description under heading 10 on diary sheet).
C	WORK INTERRUPTED No work on an element which was being worked on during the preceding days and which has not yet been completed sufficiently to allow the next element to proceed. (enter description under heading 14).
D	WORK RESTARTED on an element which was temporarily halted under 'C'. (enter description under heading 14).
E	ELEMENT COMPLETE. All work necessary to complete the element and allow the next consecutive element to start - note that not all operations may have been completed, i.e. roof silver film finish yet to be applied but otherwise the element is complete enough to allow the work to continue elsewhere unhindered. *(enter description under heading 12).
F	REPEAT WORK on an element. Record repeat work done before or after completion of the element, i.e. wall taken down and re-built, window reglazed, or making good damage. (give explanation under heading 14).
G	SNAGGING WORK on an element. Where after completion any work is not repeat work record this as snagging. (give description unde heading 14).
H	OTHER Make a brief note under heading 14 and add more detailed comments on reverse side of diary sheet.

* thereafter, diagonal line drawn through the box.

OBSERVERS SITE DIARY SHEET

Sheet no

1. Week no

2. Day

3. Date

4. Weather

5. Workforce observed on site today

6. Plant operating on site today

7. Materials delivered to site today

8. New operatives on site today and operatives leaving site today

9. New plant on site today and plant off site today

10. Work observed during the day

11. New work started

12. Existing work completed

13. Work methods

14. Progress, interruption to work, delays, problems and additional information

15. Weekend and evening working

16. Coding changes

17. Element Quick Check List

1	51
2	52
3	53
4	54
5	55
6	56
7	57
8	58
9	59
10	60
11	61
12	62
13	63
14	64
15	65
16	66
17	67
18	68
19	69
20	70
21	71
22	72
23	73
24	74
25	75
26	76
27	77
28	78
29	79
30	80
31	81
32	82
33	83
34	84
35	85
36	86
37	87
38	88
39	89
40	90
41	91
42	92
43	93
44	94
45	95
46	96
47	97
48	98
49	99
50	100

APPENDIX B
WEEKLY WEATHER CHART
SUMMARY OF RANKING

WK	MON	TUE	WED	THURS	FRI	SAT	SUN	NHP	MHLP	MJR	SCALE
1			1	1	1			3			1
2	1	1	1	1	1			5			1
3	1	1	1	1	4		1	5	1		2
4	1	1	1	1	1			5			1
5	1	1	4	1	1	1		5	1		2
6	4	4	1	1	8			2	2	1	7
7	8	1	1	1	1			4		1	3
8	1	1	1	4	4	1		5	1		2
9	1	1	4	1	4	1	4	5	1		2
10	1	1	1	1	1	1	1	7			1
11	1	4	1	1	1		8	4	1	1	2
12	1	4	1	1	1		1	5	1		2
13	1	1	1	1	X		1	5			1
14	4	1	1	1	1		8	4	1	1	3
15	4	1	1	1	1		8	4	1	1	2
16	1	1	1	8	4	1	1	5	1	1	2
17	1	1	1	1	1	1	1	7			1
18	1	1	1	1	1		1	6			1
19	1	1	1	1	1		1	6			1
20	5	1	1	1	5		1	4	2		4
21	X	X	X	1	4			1	1		3
22	1	1	1	4	1			4	1		2
23	4	1	1	1	4			3	2		4
24	1	1	9	9	9			2		3	9
25	8	7	1	1	1			3		2	6
26	1	7	1	9	1			3		2	6
27	1	1	1	4	1			4	1		2
28	X	X	X	X	X	X	X	X	X	X	X
29	X	X	X	X	X	X	X	X	X	X	X
30	9	9	9	1	1			2		3	9
31	9	7	7	1	1			2		3	9
32	8	1	4	1	9			2	1	2	8
33	8	1	1	4	4			2	2	1	7
34	8	1	9	9	1			2		3	9
35	1	9	9	1	1			3		2	6
36	1	1	1	9	9			3		2	6
37	9	9	5	1	1			2	1	2	8
38	1	1	3	1	1			4	1		2
39	1	1	1	1	1			5			1
40	1	1	1	7	1			4	1		2
41	1	1	1	1	1			5			1
42	X	X	X	X	X	X	X	X	X	X	X
43	4	1	4	1	1			2		3	4
44	1	1	9	1	1			4		1	3
45	1	8	1	1	1			4		1	3
46	1	1	1	1	1			5			1
47	1	8	1	1	1			4		1	3
48	1	1	1	1	1			5			1
49	1	1	4	7	1			3	1	1	5
50	1	7	1	1	1			4		1	3
51	1	1	1	1	1			5			1

52	7	4	1	4	1			2	2	1	3
53	X	X	X	X	X	X	X	X	X	X	X
54	4	1	1	X	1			3	1		2
55	1	1	1	1	1			5			1
56	1	1	1	1	1			5			1
57	1	1	1	1	1			5			1
58	1	1	1	1	1			5			1
59	1	1	1	1	1			5			1
60	1	1	1	1	1			5			1
61	1	1	1	1	1			5			1
62	1	1	1	1	1			5			1
63	1	1	1	1	1			5			1
64	1	1	1	1	1			5			1
65	1	1	1	1	1			5			1
66	1	1	1	1	1			5			1
67	1	1	1	1	1			5			1
68	1	1	1	1	1			5			1
69	1	1	1	1	1			5			1
70	1	1	1	1	1			5			1
71	1	4	1	1	1			4	1		2
72	1	1	1	1	1			5			1
73	1	1	1	1	1			5			1
74	1	1	1	1	1			5			1
75	1	1	1	1	1			5			1
76	1	1	1	1	1			5			1
77	1	1	1	1	1			5			1
78	1	1	1	1	1			5			1
79	1	1	1	1	1			5			1
80	X	X	X	X	X	X	X	X	X	X	X
81	X	X	X	X	X	X	X	X	X	X	X
82	1	1	1	1	1			5			1

NOTE:
For daily record:-

1 = FINE DAY — NHP = NO HOLD UP
2 = FOGGY DAY
3 = WINDY DAY — MHP = MINOR HOLD UP
4 = WET DAY
5 = COLD DAY
6 = VERY FOGGY
7 = VERY WINDY — MJR = MAJOR HOLD UP
8 = VERY WET
9 = VERY COLD

CRITERIA FOR RANKING

SCALE	CONDITIONS NHP	MHP	MJR	NUMBER OF WEEKS
1	>5	0	0	33
2	>4	1	0	3
3	>4	0	1	6
4	3	2	0	3
5	3	1	1	1
6	3	0	2	4
7	2	2	1	3
8	2	1	2	2
9	2	0	3	4
TOTAL				59

NOTE : weeks in which there are more than 5 days of observations are given a corresponding scale nearest to the days corresponding to hold up. For example a record of 6 1 0 will be scaled as 2.

APPENDIX C.1

THEORETICAL MODEL A - WEEKLY PRODUCTIVE TIME

TRANSFORMED VARIABLES -DATA FILE

NP	NT	18	5a	WK	MN	16	FL	9	12a	12b	TS	5b	1	17	7	14
0	120	0	20	1	6	2	1	3	3	1	32	24	1	1	0	15
24	328	0	44	2	6	2	1	0	3	2	80	88	4	1	0	15
24	364	16	84	3	6	2	1	2	5	3	47	128	6	2	0	15
88	424	0	40	4	6	2	1	4	7	3	49	84	6	1	0	24
243	720	0	84	5	7	1	1	1	9	5	65	136	10	2	0	24
280	632	28	76	6	7	1	1	0	7	3	74	116	11	7	0	24
214	581	52	70	7	7	1	1	1	5	2	91	125	8	3	0	15
393	700	0	108	8	7	1	1	0	6	3	88	172	10	2	0	15
440	812	0	100	9	8	1	1	0	5	2	131	156	10	2	0	15
392	844	72	88	10	8	1	1	0	5	2	144	124	10	1	8	3
460	864	52	80	11	8	1	1	0	6	2	124	120	13	2	0	3
504	928	0	100	12	8	1	1	0	6	2	132	136	16	2	4	3
375	685	0	89	13	9	1	1	0	5	2	110	137	9	1	0	3
338	935	107	52	14	9	1	1	0	6	3	138	107	16	3	69	3
670	1246	0	32	15	9	1	1	0	6	3	185	139	15	2	32	3
664	1220	92	92	16	9	1	1	0	5	3	218	132	13	2	28	3
991	1532	0	126	17	10	3	1	0	6	3	230	152	20	1	0	3
1050	1616	0	128	18	10	3	1	1	7	3	214	121	19	1	44	3
949	1574	0	119	19	10	3	1	2	8	4	179	139	21	1	24	3
728	1392	0	128	20	10	3	1	0	8	4	156	144	20	4	56	3
268	488	28	40	21	11	3	1	1	9	4	50	40	14	3	0	3
560	1084	0	25	22	11	3	1	0	8	3	149	39	23	2	26	2
538	977	0	35	23	11	3	1	0	8	3	117	39	22	4	31	2
449	1048	83	36	24	11	3	1	0	7	3	145	36	27	9	28	2
300	974	248	8	25	12	3	1	0	8	4	119	25	13	6	3	2
348	939	18	32	26	12	3	1	0	8	3	113	35	13	6	20	2
239	643	0	0	27	12	3	1	0	7	2	92	0	11	2	27	2
144	680	168	6	30	1	4	1	0	7	2	97	0	10	9	18	2
376	1021	107	40	31	1	4	1	0	9	3	108	48	19	9	25	2
343	987	108	36	32	1	4	1	0	7	2	136	36	20	8	77	2
420	1097	48	17	33	1	4	1	0	7	3	156	6	20	7	8	2
303	1155	280	64	34	2	4	1	1	8	3	139	46	19	9	64	2
262	1136	199	51	35	2	4	1	1	8	4	136	46	16	6	27	2
235	1048	140	38	36	2	4	1	0	9	4	111	51	18	6	14	2
238	995	40	29	37	2	4	1	1	10	5	97	28	21	8	3	2
198	711	8	19	38	3	4	1	0	8	3	88	8	14	2	8	2
186	565	0	8	39	3	4	1	1	8	3	68	19	15	1	0	2
190	808	63	27	40	3	4	1	0	10	3	79	23	20	3	0	2
309	1005	20	16	41	3	4	1	0	11	5	89	29	24	1	8	2
306	1224	16	32	43	4	2	1	1	14	6	82	71	25	4	32	2
160	815	80	23	44	4	2	1	0	11	5	71	30	17	3	8	2
241	986	115	2	45	4	2	1	0	10	4	98	7	18	3	0	2
338	891	5	31	46	5	2	1	0	13	4	65	40	23	1	12	4
325	739	55	7	47	5	2	1	0	13	7	56	11	21	3	5	4
685	1276	0	39	48	5	2	1	0	13	6	96	22	29	1	34	4
372	982	16	18	49	5	2	1	0	13	5	73	30	26	5	0	2
454	1087	16	12	50	5	2	1	0	11	4	97	17	23	3	62	2
351	952	0	39	51	6	2	1	1	12	4	75	47	19	1	8	2
477	1231	119	9	52	6	2	1	0	11	4	110	17	24	3	28	4
326	832	0	8	54	6	2	1	0	12	5	68	15	18	2	16	23
555	1100	0	19	55	7	1	1	1	15	6	71	37	20	1	9	4
315	698	0	13	56	7	1	1	0	8	3	85	20	13	1	0	4
235	621	0	16	57	7	1	1	0	10	2	61	9	11	1	0	4
378	973	0	20	58	7	1	1	0	12	4	78	36	18	1	10	2

377	899	0	12	59	8	1	1	0	11	3	81	12	17	1	0	4
332	824	0	10	60	8	1	1	0	13	4	47	14	14	1	1	4
388	942	0	12	61	8	1	1	1	14	4	65	32	18	1	4	23
337	837	0	8	62	8	1	1	0	11	4	73	32	19	1	0	4
345	874	0	20	63	8	1	1	1	13	5	63	49	25	1	17	23
397	922	0	8	64	9	1	1	0	12	5	75	28	16	1	31	23
384	932	0	10	65	9	1	1	0	12	5	76	13	15	1	6	23
251	696	0	26	66	9	1	1	0	10	5	66	34	15	1	1	23
417	1025	0	12	67	9	1	1	0	14	6	72	19	19	1	16	4
562	932	0	8	68	10	3	1	0	14	5	66	8	26	1	16	2
554	1122	0	38	69	10	3	1	0	13	6	83	46	25	1	0	4
393	1043	0	16	70	10	3	1	0	14	5	73	27	21	1	53	23
482	1140	0	29	71	10	3	1	2	13	5	85	33	25	2	33	4
329	1114	0	19	72	10	3	1	1	14	6	77	39	20	1	4	4
223	950	0	31	73	11	3	1	0	10	4	92	34	21	1	32	23
340	1055	0	5	74	11	3	1	0	13	4	77	56	20	1	24	23
376	1075	0	7	75	11	3	1	0	11	6	96	15	24	1	25	23
521	1409	0	21	76	11	3	1	0	14	4	98	33	23	1	13	4
278	819	0	11	77	12	3	1	0	13	6	60	37	22	1	27	4
311	1060	0	15	78	12	3	1	0	12	5	86	29	24	1	32	4
299	951	0	4	79	12	3	1	0	12	5	78	15	19	1	0	4
392	952	0	7	82	1	4	1	0	11	5	86	7	20	1	23	4
24	32	0	0	21	11	3	2	2	2	1	16	0	2	3	0	2
37	42	0	0	22	11	3	2	1	2	1	21	0	1	2	0	11
29	50	0	13	23	11	3	2	3	4	1	9	13	3	4	0	11
39	44	0	0	24	11	3	2	0	1	1	44	0	1	9	0	11
20	20	0	0	25	12	3	2	0	1	1	20	0	1	6	0	11
83	106	0	15	26	12	3	2	1	5	3	18	15	5	6	0	3
197	273	0	32	27	12	3	2	0	6	3	39	39	8	2	0	21
355	636	9	23	30	1	4	2	1	7	3	88	22	11	9	16	2
200	360	15	16	31	1	4	2	1	7	3	47	28	8	9	9	2
127	241	0	20	32	1	4	2	0	5	3	44	20	8	8	33	2
130	179	0	0	33	1	4	2	0	5	1	36	0	5	7	0	2
232	333	0	6	34	2	4	2	0	7	3	48	0	12	9	0	2
204	435	0	3	35	2	4	2	0	3	1	142	8	7	6	20	2
122	241	12	5	36	2	4	2	0	4	1	60	3	6	6	16	2
169	523	56	40	37	2	4	2	0	5	1	99	26	9	8	4	2
212	359	0	0	38	3	4	2	0	5	1	69	12	5	2	0	2
187	282	0	0	39	3	4	2	1	5	1	56	4	12	1	0	2
345	590	0	20	40	3	4	2	1	6	1	94	24	16	3	0	2
249	483	0	6	41	3	4	2	1	8	3	57	29	14	1	7	2
171	357	0	22	43	4	2	2	3	9	2	37	24	10	4	0	2
64	165	0	0	44	4	2	2	0	6	2	25	12	10	3	0	2
75	164	0	2	45	4	2	2	0	8	3	21	2	11	3	0	2
58	97	0	0	46	5	2	2	0	6	4	15	8	9	1	17	11
48	53	0	5	47	5	2	2	0	3	2	16	5	3	3	0	8
23	130	0	3	48	5	2	2	0	6	3	21	3	7	1	43	3
111	156	0	0	49	5	2	2	0	6	1	26	0	5	5	16	4
151	293	0	4	50	5	2	2	1	8	4	36	4	9	3	23	4
226	292	0	7	51	6	2	2	0	9	3	32	8	13	1	0	4
105	148	0	19	52	6	2	2	0	8	1	18	4	9	3	0	4
90	191	0	23	54	6	2	2	1	6	2	28	24	9	2	0	4
169	270	0	0	55	7	1	2	0	5	3	53	3	8	1	0	4
158	196	0	0	56	7	1	2	0	5	1	39	0	10	1	10	23
163	228	0	1	57	7	1	2	0	6	2	38	1	7	1	0	4
178	355	0	8	58	7	1	2	0	8	4	43	8	9	1	6	4
179	273	0	0	59	8	1	2	0	8	3	34	4	9	1	11	10
143	363	0	20	60	8	1	2	0	9	4	38	23	11	1	0	4
122	176	0	4	61	8	1	2	1	7	2	25	4	10	1	0	4
73	162	0	21	62	8	1	2	0	6	1	22	28	9	1	0	23

145	295	0	1	63	8	1	2	0	9	1	32	8	12	1	16	23
136	207	0	0	64	9	1	2	0	5	1	41	0	10	1	8	23
279	388	0	7	65	9	1	2	0	7	2	55	0	10	1	0	4
294	414	0	0	66	9	1	2	0	7	3	59	0	14	1	11	23
326	453	0	13	67	9	1	2	0	9	2	49	13	13	1	0	4
342	478	0	0	68	10	3	2	0	5	2	96	0	12	1	0	4
293	350	0	3	69	10	3	2	0	6	2	58	0	9	1	0	4
342	448	0	3	70	10	3	2	0	8	3	56	3	12	1	4	4
292	468	0	17	71	10	3	2	1	10	2	45	21	10	2	0	4
270	392	0	3	72	10	3	2	1	11	3	35	3	15	1	0	4
217	401	0	0	73	11	3	2	0	8	2	48	9	11	1	4	4
340	596	0	4	74	11	3	2	1	12	5	49	12	18	1	53	4
451	700	0	0	75	11	3	2	0	10	3	70	3	18	1	33	4
301	467	0	0	76	11	3	2	0	9	3	51	4	15	1	11	4
260	470	0	11	77	12	3	2	0	9	4	51	12	14	1	0	4
172	371	0	0	78	12	3	2	0	9	3	41	0	14	1	24	4
219	374	0	4	79	12	3	2	1	11	4	33	4	21	1	12	4
99	202	0	0	82	1	4	2	0	8	5	25	0	12	1	9	4
56	56	0	0	21	11	3	3	2	2	1	28	0	3	3	0	12
0	22	0	0	22	11	3	3	0	1	1	22	0	1	2	22	21
0	24	0	0	23	11	3	3	0	1	1	24	0	2	4	24	21
32	32	0	0	24	11	3	3	3	3	1	11	0	1	9	0	15
78	86	0	0	25	12	3	3	2	4	1	22	0	3	6	0	2
39	52	0	0	26	12	3	3	0	3	2	17	0	5	6	10	11
99	137	0	0	27	12	3	3	0	3	1	46	0	3	2	24	11
29	37	0	0	30	1	4	3	0	1	1	37	0	3	9	0	11
55	55	0	0	31	1	4	3	0	1	1	55	0	1	9	0	11
92	100	0	0	32	1	4	3	0	2	1	50	0	6	8	0	11
117	146	0	0	33	1	4	3	0	2	1	73	0	6	7	14	11
55	63	0	0	34	2	4	3	0	1	1	63	0	1	9	4	11
125	168	0	6	35	2	4	3	0	3	1	54	6	4	6	0	3
257	361	0	16	36	2	4	3	1	5	2	67	26	8	6	0	11
87	149	16	4	37	2	4	3	0	4	3	36	4	5	8	0	11
232	385	4	27	38	3	4	3	0	6	3	60	27	6	2	0	3
332	509	0	24	39	3	4	3	1	8	3	60	29	12	1	0	11
156	281	0	16	40	3	4	3	0	7	2	36	24	13	3	20	11
242	387	0	34	41	3	4	3	0	6	3	59	35	14	1	18	11
101	310	0	12	43	4	2	3	0	6	2	49	16	10	4	29	11
175	362	8	9	44	4	2	3	1	6	2	58	12	12	3	17	2
178	421	4	38	45	4	2	3	0	7	3	53	49	13	3	39	11
202	386	9	16	46	5	2	3	0	6	2	62	17	12	1	13	11
352	472	0	0	47	5	2	3	1	7	3	67	0	10	3	0	2
415	559	0	4	48	5	2	3	0	7	2	79	4	15	1	10	2
262	488	53	4	49	5	2	3	0	6	2	81	4	14	5	8	2
122	163	0	5	50	5	2	3	0	6	2	26	9	9	3	0	2
119	198	0	0	51	6	2	3	0	5	2	40	0	9	1	0	11
104	108	0	0	52	6	2	3	0	3	1	36	0	5	3	0	11
248	365	24	20	54	6	2	3	0	5	2	73	0	9	2	16	11
184	343	0	19	55	7	1	3	1	7	3	46	20	14	1	0	2
162	305	0	15	56	7	1	3	0	5	1	57	19	10	1	0	2
149	275	0	25	57	7	1	3	1	8	2	33	15	8	1	15	2
177	339	0	19	58	7	1	3	1	9	4	34	30	11	1	4	3
161	328	0	9	59	8	1	3	0	6	2	50	28	15	1	14	11
208	392	0	12	60	8	1	3	0	8	3	48	7	18	1	0	3
215	430	0	3	61	8	1	3	1	8	3	53	8	12	1	7	4
172	220	0	0	62	8	1	3	0	6	2	37	0	10	1	11	4
112	229	0	4	63	8	1	3	0	7	2	33	0	11	1	40	4
112	217	0	0	64	9	1	3	0	8	3	27	0	13	1	13	8
46	94	0	0	65	9	1	3	0	5	2	19	0	4	1	0	8
27	80	0	0	66	9	1	3	0	7	3	11	0	8	1	34	11

171	267	0	0	67	9	1	3	1	7	2	38	0	7	1	32	4
191	318	0	0	68	10	3	3	0	6	2	53	0	6	1	15	4
167	238	0	0	69	10	3	3	1	8	2	30	0	10	1	0	4
184	252	0	0	70	10	3	3	0	8	2	32	0	10	1	13	4
129	246	0	0	71	10	3	3	0	7	2	35	0	9	2	0	4
216	360	0	15	72	10	3	3	0	7	2	48	19	7	1	8	4
169	318	0	0	73	11	3	3	0	7	2	45	0	12	1	15	4
278	474	0	8	74	11	3	3	0	8	2	57	16	13	1	50	8
389	457	0	0	75	11	3	3	0	8	3	56	11	13	1	0	4
344	491	0	4	76	11	3	3	1	10	4	48	10	12	1	8	4
407	503	0	0	77	12	3	3	0	9	2	55	8	15	1	0	8
195	325	0	0	78	12	3	3	0	7	3	46	0	12	1	0	4
96	219	0	4	79	12	3	3	0	8	4	27	4	11	1	16	3
171	361	0	12	82	1	4	3	1	7	3	49	16	10	1	0	3

NOTE:
Number of cases = 188
NP= Productive hours
NT= Total hours before deducting management hours
FL= floor level to be tranformed to x19 during analyses
WK= Week number - not a variable
MN= Month of the year - not a variable
TS= Trade signifcant index - not a variable
Numbers at the top = variable number
5a= Supervision level (to be chosen)
5b= Management Hours (to be chosen)
12a=Trade variability (to be chosen)
12b=Trade variability (to be chosen)

APPENDIX C.2
THEORETICAL MODEL B - TRADE PRODUCTIVE TIME
TRANSFORMED VARIABLE -DATA FILE

TT	NP	NT	X18	X7	X15	X8	X1	SWH	FL
1	148	240	0	4	4	2	1	22	1
2	4788	11584	1323	297	62	6	28	2811	1
3	4999	10065	191	75	73	4	73	2688	1
4	3614	7613	0	0	40	3	19	1276	1
5	243	796	12	63	12	6	6	103	1
7	186	571	0	4	17	3	6	113	1
8	822	1929	0	0	29	5	11	260	1
9	435	1455	0	10	38	6	4	300	1
10	102	365	0	0	12	4	4	113	1
11	986	3828	592	111	53	7	22	752	1
12	118	288	15	10	13	5	4	27	1
13	1494	3473	49	36	63	7	49	1263	1
14	709	2304	30	23	73	6	49	619	1
15	4137	9901	143	352	76	5	82	3222	1
16	4	40	0	0	5	4	2	36	1
21	2609	4643	58	137	60	10	34	848	1
22	220	355	15	0	9	4	7	15	1
23	1687	4804	0	34	40	5	14	1328	1
24	359	738	23	61	5	1	4	175	1
25	370	583	0	0	6	0	4	114	1
26	56	212	0	0	7	1	2	68	1
27	209	447	0	0	8	2	2	39	1
28	9	64	0	0	3	2	2	4	1
29	16	160	0	0	4	2	1	128	1
30	36	64	0	0	3	1	1	0	1
31	126	247	0	0	6	0	2	20	1
1	0	4	0	0	1	0	1	0	2
2	1602	3292	92	123	40	11	17	799	2
3	989	1650	0	11	42	11	26	290	2
4	2633	3827	0	3	35	4	12	518	2
5	21	72	0	20	4	1	3	16	2
7	152	227	0	9	10	4	3	45	2
8	504	688	0	0	18	4	10	79	2
9	291	510	0	7	26	5	8	82	2
10	229	493	0	0	9	2	3	142	2
11	428	634	0	110	35	11	13	61	2
12	4	4	0	0	1	0	1	0	2
13	17	24	0	0	3	1	2	8	2
14	86	164	0	0	24	13	9	45	2
15	645	1215	0	55	45	10	22	315	2
18	5	5	0	0	1	0	1	0	2
21	445	608	0	32	31	13	12	94	2
22	18	37	0	0	1	0	1	10	2
23	1738	2515	0	20	28	2	14	283	2
26	93	110	0	0	6	3	1	1	2
27	37	50	0	0	4	3	2	0	2
28	0	9	0	0	1	0	1	0	2
31	104	137	0	24	5	0	1	3	2
1	0	4	0	0	1	0	1	4	3
2	1183	2069	23	21	27	6	10	507	3
3	1380	2104	0	47	44	5	34	328	3
4	1639	2290	0	0	22	2	8	252	3
5	31	67	0	36	3	2	7	0	3

7	190	362	0	0	12	2	6	135	3
8	816	1163	0	0	22	4	8	116	3
9	76	167	0	4	14	7	5	15	3
10	4	4	0	0	1	0	1	0	3
11	2164	3215	95	250	43	8	20	410	3
12	56	60	0	0	3	2	2	4	3
13	14	22	0	4	4	2	3	4	3
14	78	211	0	7	20	9	8	74	3
15	614	1477	0	137	44	7	26	445	3
21	550	696	0	50	32	9	7	21	3
23	263	380	0	0	15	3	7	32	3
26	90	149	0	0	8	0	1	83	3
27	0	5	0	0	1	0	1	5	3
28	8	16	0	0	1	0	1	0	3
31	24	24	0	0	1	0	1	0	3

NOTE:
Number of cases = 68
TT = Trade type = transformed into x14 during analysis
NP = Productive hours
NT = Total hours
FL = floor level to be transfromed to x19 during analysis
SWH= Not a variable
x13= Trade significance calculated during analysis
Formula = (PT/SUM(PT))*100

APPENDIX C.3
THEORETICAL MODEL C - ELEMENT PRODUCTIVE TIME
TRANSFORMED VARIABLE - DATA FILE

EC	NP	NT	7	FL	12A	12B	14	5B	5A	3	6	1	DT
1	2526	4858	28	1	10	5	15	622	423	48	11	11	5
2	26	201	0	1	8	3	15	3	3	11	4	5	5
3	1576	2409	108	1	6	3	15	114	69	38	8	3	5
4	24	32	0	1	1	1	13	8	8	1	0	1	5
5	808	1406	65	1	6	3	24	215	148	16	0	9	5
6	4175	7831	110	1	5	2	3	1224	801	19	2	9	2
7	1840	2904	153	1	8	2	15	221	169	33	8	10	1
8	1027	1643	118	1	6	1	21	163	116	26	7	8	4
9	4270	8439	346	1	9	1	2	261	172	53	7	6	3
10	912	1249	21	1	12	3	15	7	7	48	8	4	5
11	772	1664	39	1	7	2	3	36	36	39	5	8	4
12	246	353	4	1	4	1	21	0	0	22	7	4	4
13	91	222	4	1	1	1	11	0	0	11	7	4	4
14	886	1600	98	1	8	1	11	56	56	44	8	9	4
15	439	763	8	1	5	2	3	22	10	30	5	7	4
16	266	559	51	1	4	1	5	23	19	9	4	2	3
17	659	1030	0	1	5	2	8	7	7	19	10	4	1
18	449	671	0	1	5	2	8	8	8	17	3	5	1
19	17	20	0	1	1	1	7	0	0	1	0	2	3
20	177	219	0	1	2	1	3	0	0	11	5	4	5
21	60	65	0	1	1	1	8	0	0	1	0	1	1
22	182	289	4	1	4	1	3	20	20	12	4	6	3
23	575	1067	19	1	6	1	9	27	27	39	6	4	5
24	3398	5236	5	1	5	1	4	59	59	40	3	6	5
25	999	2124	26	1	4	1	23	57	57	36	4	4	5
26	675	1150	8	1	1	1	23	5	5	24	5	4	5
27	64	130	0	1	2	1	23	0	0	4	1	1	5
28	492	733	0	1	5	1	25	23	14	13	4	6	5
29	351	438	0	1	8	3	4	0	0	22	7	6	5
30	41	45	0	1	3	1	15	0	0	3	2	2	5
31	426	595	17	1	7	3	3	28	8	20	9	10	5
32	37	72	0	1	5	2	11	0	0	5	4	3	4
33	22	108	0	1	3	1	2	0	0	3	0	2	5
8	8	28	16	2	1	1	21	0	0	3	2	3	4
9	1530	2298	142	2	3	1	2	68	57	37	12	5	3
10	323	387	0	2	7	2	15	0	0	21	8	4	5
11	1027	1556	52	2	9	3	3	169	112	22	6	9	4
12	207	279	4	2	4	1	21	5	5	21	8	5	4
13	4	4	0	2	1	1	11	0	0	1	0	1	4
14	332	469	71	2	4	1	11	0	0	21	7	5	4
15	326	434	9	2	2	2	3	9	5	22	7	5	4
16	21	32	0	2	1	1	5	0	0	2	0	2	3
17	525	893	16	2	4	2	8	6	6	17	7	3	1
18	232	321	24	2	3	2	8	4	4	12	2	4	1
19	8	8	0	2	1	1	7	0	0	1	0	1	3
20	92	112	0	2	3	1	3	0	0	6	3	4	5
21	40	40	0	2	1	1	8	0	0	2	1	4	1
22	87	121	0	2	3	1	3	0	0	7	1	4	3
23	304	462	7	2	3	1	9	12	12	27	7	3	5
24	2546	3358	5	2	5	1	4	8	8	35	4	4	5
25	798	1092	16	2	4	1	23	10	10	25	2	4	5
26	961	1135	4	2	2	1	23	4	4	20	6	4	5
27	8	23	0	2	1	1	23	0	0	2	0	1	5

28	109	122	0	2	1	1	26	2	2	8	5	3	5
29	227	295	3	2	8	3	15	4	4	26	8	6	5
30	19	19	0	2	1	1	15	0	0	1	0	1	5
31	9	9	0	2	2	2	2	0	0	2	0	2	5
32	272	385	46	2	8	3	11	28	16	11	6	8	4
8	174	251	59	3	3	1	21	5	5	17	6	6	4
9	1440	2464	65	3	7	1	2	42	42	31	5	5	3
10	181	281	23	3	9	2	15	0	0	21	8	4	5
11	1177	1771	136	3	9	3	3	147	125	23	7	7	4
12	186	199	0	3	3	1	21	0	0	14	5	2	4
13	1211	1645	100	3	4	1	11	56	56	37	11	7	4
14	852	1208	156	3	3	1	11	4	4	33	8	6	4
15	364	632	13	3	2	5	7	19	11	23	9	5	4
16	31	35	0	3	2	1	5	0	0	2	1	3	3
17	597	744	0	3	3	1	8	8	8	17	1	3	1
18	184	256	0	3	3	1	8	0	0	12	5	3	1
20	200	214	0	3	2	1	3	0	0	9	5	3	5
21	58	63	0	3	1	1	8	0	0	3	2	2	1
22	162	248	0	3	4	1	3	0	0	11	4	5	3
23	214	339	7	3	5	1	11	8	8	22	9	4	5
24	1618	2113	0	3	3	1	4	7	7	21	2	4	5
25	113	143	0	3	1	1	23	3	3	11	5	3	5
26	146	202	0	3	1	1	23	0	0	7	4	2	5
28	130	185	0	3	3	1	26	0	0	11	1	3	5
29	87	104	0	3	4	1	15	4	4	9	6	4	5
30	38	47	0	3	2	1	15	0	0	3	2	2	5

NOTE:
Number of cases = 79
EC = elemental classification
= to be transformed to x4 during analysis
DT = Design type to be transformed to x10 during analysis
FL = floor level to transformed to x19 during analysis
numbers at top of table correspond to variables
12A and 12B = variable x12 to be chosen during analysis
5A and 5B = variable x5 to be chosen during analysis

APPENDIX C.4
THOERETICAL MODEL D - OPERATIONS PRODUCTIVE TIME
TRANSFORMED VARIABLE - DATA FILE

EC	DT	12A	12B	14	FL	2	NP	NT	3	6	SP	5	DQP	7
1	5	2	1	2	1	0	8	12	2	1	0	0	0	0
1	5	5	3	15	1	17	562	829	10	1	32	140	0	0
1	5	2	1	15	1	0	0	84	3	1	0	0	0	0
1	5	4	2	15	1	5	191	222	11	6	2	8	0	0
1	5	6	1	3	1	41	1233	2014	22	6	52	223	75	21
1	5	6	3	15	1	20	712	989	15	5	12	50	14	4
1	5	4	1	2	1	3	89	152	7	4	3	12	0	0
1	5	2	1	2	1	0	9	13	2	1	0	0	0	0
1	5	2	1	29	1	3	19	160	6	4	0	0	0	0
1	5	5	1	21	1	6	190	299	9	3	0	0	11	3
1	5	1	1	2	1	2	72	85	3	0	0	0	0	0
2	5	3	1	9	1	16	0	32	1	0	57	4	0	0
2	5	2	1	16	1	18	4	36	5	3	0	0	0	0
2	5	1	1	19	1	8	0	16	2	0	0	0	0	0
2	5	3	2	4	1	12	22	25	1	0	43	3	0	0
2	5	3	2	15	1	46	0	93	6	0	0	0	0	0
3	5	5	2	13	1	27	445	640	24	6	45	50	11	12
3	5	5	1	15	1	44	656	1060	31	7	46	51	81	88
3	5	6	1	2	1	29	475	706	23	9	9	11	8	8
4	5	1	1	13	1	100	24	32	1	0	100	8	0	0
5	5	1	1	24	1	2	0	32	1	0	0	0	0	0
5	5	3	1	24	1	48	331	673	6	1	75	132	88	57
5	5	1	1	24	1	4	16	52	3	2	2	4	6	4
5	5	3	1	24	1	2	8	28	3	2	5	8	0	0
5	5	2	1	3	1	24	238	332	9	1	14	24	0	0
5	5	2	1	21	1	9	64	120	4	0	2	4	6	4
5	5	2	1	15	1	1	7	15	2	1	0	0	0	0
5	5	1	1	3	1	1	8	8	1	0	0	0	0	0
5	5	3	1	15	1	10	136	148	8	0	2	4	0	0
6	2	1	1	21	1	0	0	4	1	0	0	0	0	0
6	2	4	2	13	1	24	851	1883	17	1	24	215	56	62
6	2	3	1	15	1	5	235	360	11	1	5	49	0	0
6	2	5	1	3	1	35	1610	2760	16	0	32	287	15	16
6	2	4	1	21	1	14	610	1094	13	0	12	112	29	32
6	2	4	1	15	1	8	181	637	10	0	15	132	0	0
6	2	3	1	3	1	4	227	319	10	0	4	36	0	0
6	2	3	1	15	1	10	443	751	9	1	8	72	0	0
6	2	3	1	15	1	0	17	23	2	0	0	0	0	0
7	1	5	2	15	1	13	213	387	12	4	16	33	12	19
7	1	5	2	15	1	8	150	220	9	2	7	14	6	9
7	1	4	2	3	1	3	49	83	7	3	2	5	0	0
7	1	4	1	3	1	31	582	886	22	5	24	48	18	27
7	1	5	2	21	1	7	84	199	10	3	11	22	19	29
7	3	5	1	15	1	18	301	530	14	3	26	53	16	25
7	3	4	1	15	1	8	190	230	11	3	11	23	8	12
7	1	2	1	3	1	4	82	102	9	2	0	0	0	0
7	5	4	1	15	1	2	58	69	2	1	2	4	0	0
7	5	4	3	21	1	7	132	200	9	6	0	0	20	31
8	4	1	1	21	1	1	0	15	2	1	0	0	0	0
8	4	5	1	21	1	39	280	634	15	5	72	84	35	41
8	4	3	1	21	1	21	284	349	13	5	14	16	3	4
8	4	2	1	21	1	8	114	125	5	1	3	4	0	0
8	4	3	1	21	1	13	112	207	9	4	7	8	55	65

8	4	1	1	21	1	10	122	158	6	1	0	0	7	8
8	4	5	1	21	1	9	116	144	7	5	3	4	0	0
8	4	2	1	21	1	1	0	12	1	0	0	0	0	0
9	3	1	1	2	1	0	0	4	1	0	0	0	0	0
9	3	6	1	2	1	39	1687	3261	37	5	55	139	46	158
9	3	8	1	2	1	45	1717	3786	48	9	30	75	50	173
9	3	2	1	2	1	7	336	556	25	11	4	10	0	0
9	1	6	1	2	1	8	412	655	17	4	12	29	3	11
9	5	4	1	3	1	2	118	178	12	4	0	0	1	4
10	5	10	1	15	1	67	577	841	37	8	57	4	100	21
10	5	5	1	15	1	19	203	233	22	12	0	0	0	0
10	5	8	2	4	1	10	100	125	16	8	0	0	0	0
10	5	4	4	15	1	4	32	49	4	2	43	3	0	0
11	4	1	1	15	1	0	3	3	1	0	0	0	0	0
11	4	7	4	13	1	25	127	410	9	3	80	31	13	5
11	4	4	1	3	1	25	199	411	17	4	10	4	41	16
11	4	1	1	21	1	0	0	5	1	0	0	0	0	0
11	4	4	1	13	1	9	8	147	17	6	0	0	46	18
11	4	1	1	15	1	0	0	3	1	0	0	0	0	0
11	4	2	2	15	1	3	35	51	5	3	0	0	0	0
11	4	5	1	3	1	38	400	635	11	2	10	5	0	0
12	2	2	2	8	1	2	5	9	2	1	0	0	0	0
12	2	1	1	21	1	43	103	153	11	4	0	0	40	4
12	4	2	1	21	1	54	139	191	13	4	0	0	60	6
13	4	1	1	11	1	89	91	198	9	6	0	0	0	0
13	4	1	1	11	1	2	0	4	1	0	0	0	0	0
13	4	1	1	11	1	7	0	16	2	1	0	0	100	4
13	4	1	1	11	1	2	0	4	1	0	0	0	0	0
14	4	1	1	11	1	0	3	7	2	1	7	4	0	0
14	4	6	1	11	1	63	484	1001	34	9	60	36	87	85
14	4	1	1	11	1	1	13	13	1	0	0	0	0	0
14	4	1	1	11	1	1	0	8	2	1	0	0	0	0
14	4	2	1	11	1	11	103	173	6	2	18	11	0	0
14	4	1	1	11	1	14	172	222	18	9	0	0	13	13
14	4	3	1	22	1	8	72	131	3	1	15	9	0	0
14	4	2	1	3	1	1	20	20	2	1	0	0	0	0
14	4	1	1	11	1	2	19	26	2	0	0	0	0	0
15	4	1	1	22	1	1	5	5	1	0	0	0	0	0
15	4	2	1	3	1	2	9	16	3	2	0	0	0	0
15	4	3	1	7	1	38	156	291	17	4	0	0	50	4
15	4	2	1	3	1	34	117	260	14	2	0	0	50	4
15	4	1	1	3	1	3	15	24	3	2	0	0	0	0
15	5	2	1	3	1	5	24	36	4	1	0	0	0	0
15	4	1	1	22	1	17	114	132	3	0	100	10	0	0
16	3	5	1	5	1	88	212	493	7	3	100	19	100	51
16	1	1	1	5	1	6	27	35	2	0	0	0	0	0
16	1	1	1	5	1	6	27	32	2	0	0	0	0	0
17	1	1	1	21	1	1	8	8	1	0	0	0	0	0
17	1	4	2	10	1	52	262	535	11	6	43	3	0	0
17	1	1	1	5	1	1	5	8	1	0	0	0	0	0
17	3	1	1	8	1	47	383	479	12	6	57	4	0	0
18	1	2	1	3	1	3	8	20	2	1	0	0	0	0
18	4	1	1	30	1	23	126	154	5	1	0	0	0	0
18	1	1	1	8	1	9	58	62	5	3	0	0	0	0
18	5	1	1	8	1	63	254	421	8	0	100	8	0	0
18	1	3	1	25	1	2	4	15	3	2	0	0	0	0
19	3	1	1	7	1	54	8	11	1	0	0	0	0	0
19	3	1	1	7	1	46	9	9	1	0	0	0	0	0
20	1	2	1	3	1	47	102	102	3	1	0	0	0	0
20	5	1	1	3	1	8	18	18	2	1	0	0	0	0

20	3	1	1	3	1	9	19	19	3	1	0	0	0	0
20	5	1	1	3	1	36	38	79	3	2	0	0	0	0
21	1	1	1	8	1	100	60	65	1	0	0	0	0	0
22	5	2	1	9	1	9	11	25	3	2	20	4	0	0
22	3	2	1	3	1	15	28	43	3	1	0	0	100	4
22	3	1	1	3	1	52	109	149	4	0	80	16	0	0
22	3	1	1	3	1	4	3	11	2	1	0	0	0	0
22	3	1	1	3	1	13	20	38	4	3	0	0	0	0
22	5	2	1	3	1	8	11	23	3	2	0	0	0	0
23	5	1	1	9	1	1	0	7	1	0	14	4	0	0
23	5	2	1	9	1	3	0	30	2	1	0	0	0	0
23	5	2	1	11	1	10	55	105	8	6	0	0	0	0
23	5	3	1	9	1	16	61	173	11	3	43	12	47	9
23	5	4	1	9	1	71	460	752	31	7	43	12	53	10
24	5	1	1	21	1	0	0	5	1	0	0	0	0	0
24	5	5	1	4	1	91	3154	4783	39	3	83	68	100	5
24	5	1	1	4	1	5	161	250	16	6	0	0	0	0
24	5	2	1	4	1	3	84	182	15	9	17	14	0	0
24	5	1	1	4	1	0	0	13	1	0	0	0	0	0
24	5	1	1	4	1	0	0	4	1	0	0	0	0	0
25	5	3	1	23	1	87	857	1853	35	5	84	48	81	21
25	5	1	1	23	1	11	139	224	18	4	16	9	19	5
25	5	2	1	23	1	2	3	47	4	3	0	0	0	0
26	5	1	1	23	1	89	589	1026	24	5	100	5	100	8
26	5	1	1	23	1	9	83	101	6	2	0	0	0	0
26	5	1	1	23	1	1	4	11	2	1	0	0	0	0
26	5	1	1	23	1	1	0	12	2	1	0	0	0	0
27	5	2	1	23	1	100	64	130	4	1	0	0	0	0
28	5	2	2	4	1	3	25	25	2	1	0	0	0	0
28	5	1	1	4	1	2	13	18	2	1	0	0	0	0
28	5	1	1	4	1	1	5	5	1	6	0	0	0	0
28	5	2	1	31	1	6	24	43	4	2	29	4	0	0
28	5	1	1	26	1	14	48	106	6	1	0	0	0	0
28	5	3	1	25	1	73	378	538	6	0	71	10	0	0
29	5	5	2	15	1	17	58	77	11	6	0	0	0	0
29	5	1	1	15	1	1	0	4	1	0	0	0	0	0
29	5	2	1	4	1	26	109	112	8	1	0	0	0	0
29	5	1	1	3	1	4	16	16	1	0	0	0	0	0
29	5	3	1	2	1	22	72	97	5	1	0	0	0	0
29	5	3	3	15	1	14	42	62	6	4	0	0	0	0
29	5	1	1	15	1	16	53	71	3	0	0	0	0	0
30	5	3	3	15	1	66	28	28	2	1	0	0	0	0
30	5	1	1	15	1	38	13	17	1	0	0	0	0	0
31	5	3	2	13	1	11	28	67	3	1	33	4	0	0
31	5	2	1	15	1	5	13	31	1	0	33	4	0	0
31	5	1	1	15	1	2	9	9	1	0	0	0	0	0
31	5	3	1	3	1	33	133	197	9	4	0	0	47	8
31	5	3	1	21	1	16	84	97	6	1	33	4	0	0
31	5	3	1	15	1	10	31	60	7	4	0	0	53	9
31	5	1	1	3	1	5	29	29	3	2	0	0	0	0
31	5	2	2	21	1	7	40	40	3	2	0	0	0	0
31	5	2	2	21	1	6	36	38	3	2	0	0	0	0
31	5	2	2	15	1	4	23	27	3	1	0	0	0	0
32	4	2	1	11	1	48	30	34	2	1	0	0	0	0
32	4	2	1	3	1	31	0	22	2	1	0	0	0	0
32	4	2	1	11	1	21	7	15	2	1	0	0	0	0
33	5	3	1	2	1	96	22	104	3	0	0	0	0	0
33	5	1	1	2	1	4	0	4	1	0	0	0	0	0
8	4	1	1	21	2	13	0	4	1	0	0	0	0	0
8	4	1	1	21	2	58	0	16	1	0	0	0	100	16

8	4	1	1	21	2	29	8	8	1	0	0	0	0	0
9	3	2	1	2	2	36	545	1081	19	6	41	33	61	87
9	3	2	1	2	2	53	762	1591	28	9	46	37	39	55
9	3	1	1	2	2	8	158	232	10	5	0	0	0	0
9	1	1	1	2	2	2	49	52	4	3	4	3	0	0
9	5	1	1	2	2	1	16	42	5	3	10	8	0	0
10	5	6	2	15	2	75	254	289	17	6	0	0	0	0
10	5	3	1	15	2	18	55	69	6	4	0	0	0	0
10	5	3	1	8	2	5	7	21	2	1	0	0	0	0
10	5	2	2	15	2	2	8	8	1	0	0	0	0	0
11	4	1	1	15	2	0	0	5	1	0	0	0	0	0
11	4	5	2	15	2	9	88	137	6	4	25	28	25	13
11	4	3	1	3	2	36	368	559	18	4	26	29	8	4
11	4	2	1	21	2	16	172	244	8	6	18	20	0	0
11	4	4	1	15	2	16	152	250	10	4	28	31	6	3
11	4	7	2	15	2	14	153	213	11	4	4	4	62	32
11	4	2	2	3	2	8	79	121	6	3	0	0	0	0
11	4	2	1	14	2	1	8	16	1	0	0	0	0	0
11	4	2	2	3	2	1	7	12	2	0	0	0	0	0
12	2	1	1	3	2	14	23	39	2	1	0	0	0	0
12	4	1	1	21	2	3	9	9	2	1	0	0	0	0
12	2	1	1	15	2	1	0	4	1	0	0	0	100	4
12	2	2	1	21	2	54	104	150	11	3	0	0	0	0
12	4	1	1	21	2	28	70	78	7	3	100	5	0	0
13	4	1	1	11	2	100	4	4	1	0	0	0	0	0
14	4	3	1	11	2	64	199	299	15	6	0	0	86	61
14	4	2	1	11	2	2	6	10	2	1	0	0	0	0
14	4	1	1	11	2	9	43	43	3	2	0	0	0	0
14	4	1	1	11	2	13	55	61	4	1	0	0	0	0
14	4	1	1	11	2	12	29	57	6	1	0	0	14	10
15	4	1	1	7	2	1	4	4	1	0	0	0	0	0
15	4	1	1	7	2	46	141	198	11	4	100	9	0	0
15	4	1	1	3	2	44	152	191	10	3	0	0	100	5
15	4	1	1	3	2	0	2	2	1	0	0	0	0	0
15	5	1	1	3	2	9	28	40	3	0	0	0	0	0
16	3	1	1	5	2	23	0	7	1	0	0	0	0	0
16	1	1	1	5	2	77	21	25	2	0	0	0	0	0
17	1	4	1	10	2	60	246	537	13	7	100	6	100	16
17	1	1	1	10	2	1	0	5	1	0	0	0	0	0
17	3	1	1	8	2	39	280	352	8	3	0	0	0	0
18	4	2	1	30	2	44	108	141	5	0	0	0	100	24
18	1	1	1	8	2	14	29	45	3	2	100	4	0	0
18	5	1	1	8	2	37	95	119	4	0	0	0	0	0
18	1	1	1	3	2	5	0	15	1	0	0	0	0	0
19	3	1	1	7	2	100	8	8	1	0	0	0	0	0
20	1	3	1	3	2	85	80	95	5	2	0	0	0	0
20	3	1	1	3	2	8	9	9	2	0	0	0	0	0
20	5	1	1	3	2	7	4	8	1	0	0	0	0	0
21	1	1	1	8	2	43	17	17	1	0	0	0	0	0
21	1	1	1	8	2	12	5	5	1	0	0	0	0	0
21	1	1	1	8	2	25	10	10	1	0	0	0	0	0
21	1	1	1	8	2	20	8	8	1	0	0	0	0	0
22	5	1	1	9	2	27	33	33	4	0	0	0	0	0
22	3	1	1	3	2	52	44	63	3	1	0	0	0	0
22	3	1	1	3	2	15	10	18	2	1	0	0	0	0
22	3	1	1	28	2	6	0	8	1	0	0	0	0	0
23	5	2	1	11	2	9	39	42	6	4	0	0	0	0
23	5	1	1	9	2	34	94	147	11	4	0	0	100	7
23	5	2	1	9	2	57	171	263	19	5	100	12	0	0
24	5	4	1	4	2	85	2248	2851	33	5	42	14	100	5

24	5	1	1	4	2	5	143	178	10	2	0	0	0	0
24	5	2	1	4	2	10	151	320	19	7	58	19	0	0
24	5	1	1	4	2	0	4	9	2	1	0	0	0	0
25	5	4	1	23	2	90	740	981	24	3	60	6	50	8
25	5	1	1	23	2	5	41	55	6	4	0	0	50	8
25	5	1	1	23	2	3	17	28	2	1	0	0	0	0
25	5	1	1	23	2	3	0	28	3	0	40	4	0	0
26	5	1	1	23	2	0	0	5	1	0	0	0	0	0
26	5	2	1	23	2	72	695	813	19	5	0	0	100	4
26	5	1	1	23	2	7	62	84	9	2	0	0	0	0
26	5	1	1	23	2	21	204	234	13	5	100	4	0	0
27	5	1	1	23	2	100	8	23	2	0	0	0	0	0
28	5	1	1	4	2	6	8	8	1	0	0	0	0	0
28	5	1	1	4	2	7	9	9	2	1	0	0	0	0
28	5	1	1	26	2	86	93	106	6	3	100	2	0	0
29	5	3	1	15	2	27	59	80	11	6	0	0	0	0
29	5	1	1	4	2	13	32	40	3	1	100	4	100	3
29	5	1	1	15	2	1	4	4	1	0	0	0	0	0
29	5	5	1	2	2	21	49	61	4	3	0	0	0	0
29	5	6	1	15	2	20	39	59	10	7	0	0	0	0
29	5	1	1	15	2	18	44	52	3	0	0	0	0	0
30	5	1	1	15	2	100	19	19	1	0	0	0	0	0
31	5	1	1	21	2	47	4	4	1	0	0	0	0	0
31	5	1	1	2	2	53	5	5	1	0	0	0	0	0
32	4	2	1	11	2	11	40	44	4	1	0	0	0	0
32	4	1	1	15	2	8	29	29	1	0	0	0	0	0
32	4	1	1	21	2	21	68	80	1	0	75	12	0	0
32	4	1	1	2	2	14	27	55	2	0	25	4	0	0
32	4	4	2	3	2	10	25	40	3	1	0	0	24	11
32	4	4	1	22	2	13	32	51	2	1	0	0	0	0
32	4	2	1	11	2	14	20	55	5	3	0	0	76	35
32	4	1	1	8	2	8	32	32	1	0	0	0	0	0
8	4	1	1	21	3	4	11	11	2	0	0	0	0	0
8	4	2	1	21	3	30	54	76	6	2	0	0	20	12
8	4	1	1	21	3	16	37	40	4	3	0	0	7	4
8	4	1	1	3	3	9	9	23	2	1	100	5	15	9
8	4	1	1	21	3	25	28	62	5	2	0	0	58	34
8	4	1	1	21	3	16	36	39	3	2	0	0	0	0
9	3	3	1	2	3	23	380	577	17	3	16	7	15	10
9	3	6	1	2	3	47	581	1147	25	6	54	23	78	51
9	3	1	1	2	3	14	217	348	12	5	0	0	0	0
9	1	1	1	2	3	3	55	63	5	3	0	0	0	0
9	5	2	1	3	3	13	207	329	14	4	31	13	6	4
10	5	8	2	15	3	57	107	161	15	7	0	0	81	19
10	5	3	2	15	3	18	47	52	7	5	0	0	0	0
10	5	5	1	8	3	15	8	41	4	2	0	0	0	0
10	5	3	1	15	3	10	19	27	4	2	0	0	17	4
11	4	6	2	3	3	17	249	295	6	1	5	6	0	0
11	4	3	1	3	3	27	346	471	12	3	13	16	0	0
11	4	2	1	21	3	15	216	263	9	3	3	4	0	0
11	4	5	1	15	3	24	155	423	9	2	68	85	56	76
11	4	5	1	15	3	15	167	272	10	4	11	14	44	60
11	4	2	1	3	3	1	22	22	4	1	0	0	0	0
11	4	2	2	15	3	1	22	26	4	2	0	0	0	0
12	2	2	1	21	3	45	86	90	7	2	0	0	0	0
12	4	2	1	21	3	55	100	109	7	3	0	0	0	0
13	4	1	1	11	3	45	563	739	23	10	29	16	53	53
13	4	1	1	11	3	1	16	16	1	0	0	0	0	0
13	4	2	1	11	3	6	85	106	5	3	0	0	0	0
13	4	1	1	11	3	8	117	132	7	4	0	0	0	0

13	4	3	1	11	3	28	292	466	17	9	71	41	47	47
13	4	2	2	3	3	2	4	28	2	1	0	0	0	0
13	4	1	1	11	3	10	135	158	3	0	0	0	0	0
14	4	2	1	11	3	78	663	945	25	1	0	0	86	134
14	4	1	1	3	3	0	5	5	1	0	0	0	0	0
14	4	1	1	11	3	4	45	48	5	3	0	0	0	0
14	4	1	1	11	3	2	26	26	2	1	0	0	0	0
14	4	2	1	11	3	14	113	172	11	7	100	4	5	8
14	4	1	1	11	3	1	0	14	1	0	0	0	9	14
15	4	2	2	7	3	3	11	22	3	1	0	0	0	0
15	4	2	1	7	3	60	218	378	14	6	62	8	0	0
15	4	1	1	3	3	28	103	178	10	6	38	5	100	13
15	4	1	1	3	3	7	20	42	2	0	0	0	0	0
15	5	1	1	3	3	2	12	12	1	0	0	0	0	0
16	3	1	1	5	3	11	0	4	1	0	0	0	0	0
16	1	1	1	5	3	21	7	7	1	0	0	0	0	0
16	1	1	1	5	3	68	24	24	1	0	0	0	0	0
17	1	1	1	8	3	1	4	4	1	0	0	0	0	0
17	1	1	1	8	3	1	5	5	1	0	0	0	0	0
17	3	3	1	8	3	98	588	735	18	1	100	8	0	0
18	1	1	1	10	3	2	4	4	1	0	0	0	0	0
18	1	1	1	8	3	91	173	234	9	3	0	0	0	0
18	5	2	1	8	3	7	8	18	2	1	0	0	0	0
20	1	2	1	3	3	68	136	145	4	0	0	0	0	0
20	5	1	1	3	3	6	12	12	2	1	0	0	0	0
20	5	2	1	3	3	26	52	57	5	4	0	0	0	0
21	1	1	1	8	3	52	28	33	2	1	0	0	0	0
21	1	1	1	8	3	48	30	30	3	2	0	0	0	0
22	5	1	1	9	3	3	8	8	1	0	0	0	0	0
22	3	1	1	3	3	7	17	17	2	1	0	0	0	0
22	3	2	1	3	3	32	52	80	4	2	0	0	0	0
22	3	1	1	3	3	27	23	67	4	3	0	0	0	0
22	5	3	1	3	3	31	62	77	3	1	0	0	0	0
23	5	2	1	11	3	36	95	124	8	2	0	0	43	3
23	5	1	1	11	3	40	84	136	8	4	0	0	0	0
23	5	2	1	9	3	10	25	34	3	2	0	0	57	4
23	5	4	1	9	3	13	10	46	8	5	100	8	0	0
24	5	3	1	4	3	90	1446	1906	21	2	100	18	0	0
24	5	1	1	4	3	6	114	134	11	3	0	0	0	0
24	5	1	1	4	3	2	51	51	6	4	0	0	0	0
24	5	1	1	4	3	1	7	22	1	0	0	0	0	0
25	5	1	1	23	3	15	21	21	4	2	0	0	0	0
25	5	1	1	23	3	82	92	117	9	5	100	3	0	0
25	5	1	1	23	3	3	0	4	1	0	0	0	0	0
26	5	1	1	23	3	96	138	195	8	4	0	0	0	0
26	5	1	1	23	3	4	8	8	1	0	0	0	0	0
28	5	1	1	4	3	9	16	16	2	0	0	0	0	0
28	5	1	1	31	3	13	24	24	1	0	0	0	0	0
28	5	1	1	26	3	78	90	145	8	0	0	0	0	0
29	5	2	1	4	3	13	13	13	3	2	0	0	0	0
29	5	1	1	15	3	4	4	4	1	0	0	0	0	0
29	5	2	2	3	3	15	16	16	1	0	0	0	0	0
29	5	3	1	15	3	68	54	71	5	4	100	4	0	0
30	5	1	1	15	3	60	25	29	2	1	0	0	0	0
30	5	2	1	15	3	40	14	19	1	0	0	0	0	0

NOTE:
Number of cases = 348
EC = elemental classification
= to be transformed to x4 during analysis

DT = Design type to be transformed to x10 during analysis
FL = Floor level to be transformed to x19 during analysis
numbers at top of table correspond to variables
12A and 12B = variable x12 to be chosen during analysis
SP and DQP not a variable

APPENDIX C.5
THEORETICAL MODEL E - GANGS PRODUCTIVE TIME MODEL
TRANSFORMED VARIABLE - DATA FILE

NP	NT	TT	FL	EC	13	7	1	15	NV	8	11	5A	5B	TH	5C
37	49	1	1	1	5	14	1	4	3	2	5	622	62	204	44
81	110	2	1	1	10	57	7	13	5	4	18	622	390	439	53
138	224	3	1	1	21	0	5	20	7	6	19	622	546	894	379
1	1	12	1	1	0	0	1	1	1	0	3	622	8	4	6
97	174	13	1	1	16	0	6	28	7	6	23	622	622	696	506
43	67	14	1	1	6	11	6	19	7	6	24	622	566	267	504
147	280	15	1	1	27	18	8	35	9	8	26	622	622	1120	605
0	2	16	1	1	0	0	1	1	1	0	4	622	168	8	24
81	115	21	1	1	11	0	3	10	5	4	9	622	316	461	160
4	36	29	1	1	3	0	1	3	3	2	1	622	0	144	168
0	7	2	1	2	14	0	1	2	2	1	3	3	0	28	0
1	3	3	1	2	6	0	2	2	2	1	5	3	3	11	3
3	3	4	1	2	5	0	1	1	1	0	2	3	3	10	0
0	4	9	1	2	8	0	1	1	1	0	2	3	0	20	0
0	6	13	1	2	12	0	3	5	1	0	7	3	0	24	0
2	15	15	1	2	30	0	3	4	3	2	7	3	3	58	3
1	8	16	1	2	16	0	1	5	4	3	2	3	0	32	0
0	4	19	1	2	8	0	1	2	2	1	0	3	0	16	0
66	99	2	1	3	22	15	3	16	10	9	13	114	92	397	43
15	21	3	1	3	5	0	3	11	7	6	13	114	92	85	33
82	124	13	1	3	22	19	3	26	7	6	13	114	92	494	94
20	33	14	1	3	11	0	3	17	9	8	13	114	92	174	87
209	283	15	1	3	39	65	3	32	7	6	13	114	92	1133	113
2	3	21	1	3	1	0	1	2	2	1	5	114	18	13	10
6	6	13	1	4	0	0	1	1	1	0	0	8	8	24	8
61	66	3	1	5	8	0	2	8	3	2	1	215	51	269	27
7	9	13	1	5	1	0	3	5	3	2	6	215	156	36	52
0	1	14	1	5	1	0	2	2	2	1	3	215	0	8	12
37	52	15	1	5	20	6	6	10	2	1	9	215	207	206	99
10	22	21	1	5	17	0	1	3	2	1	1	215	4	88	24
88	146	24	1	5	53	94	4	5	2	1	4	215	160	585	164
451	622	3	1	6	31	15	6	17	2	1	17	1224	1097	2539	1219
131	241	13	1	6	17	7	6	16	1	0	16	1224	1041	963	1219
55	102	14	1	6	6	0	7	17	4	3	19	1224	1192	406	1219
256	459	15	1	6	35	49	8	19	2	1	21	1224	1224	1834	1224
147	216	21	1	6	11	29	3	13	1	0	7	1224	582	865	1064
1	2	2	1	7	0	0	2	2	2	1	8	221	26	8	19
191	261	3	1	7	30	17	10	24	7	6	32	221	221	1045	213
1	1	4	1	7	0	0	1	1	1	0	4	221	83	5	10
0	3	5	1	7	0	8	1	1	1	0	3	221	27	12	0
24	52	13	1	7	19	2	7	14	4	3	25	221	221	206	177
30	43	14	1	7	5	10	9	17	6	5	31	221	221	204	197
178	265	15	1	7	42	64	10	26	6	5	32	221	221	1061	191
29	36	21	1	7	4	0	2	7	5	4	7	221	25	143	53
15	21	3	1	8	4	7	3	7	5	4	10	163	140	85	52
10	10	8	1	8	0	0	3	1	1	0	7	163	148	40	24
3	5	13	1	8	2	0	3	4	3	2	7	163	24	21	4
1	3	14	1	8	2	0	2	2	2	1	8	163	132	11	48
1	13	15	1	8	2	4	3	6	5	4	10	163	132	52	120
226	318	21	1	8	77	89	8	22	9	8	14	163	163	1272	136
1012	1835	2	1	9	85	78	6	52	8	7	21	261	261	7415	261
39	63	3	1	9	3	0	4	17	7	6	20	261	256	251	59
2	4	4	1	9	0	0	1	1	1	0	7	261	51	15	4

0	1	11	1	9	0	1	1	1	1	0	5	261	148	5	0
0	24	13	1	9	3	1	3	13	8	7	17	261	256	94	114
2	13	14	1	9	1	0	4	12	8	7	20	261	256	57	107
12	78	15	1	9	6	18	5	32	10	9	21	261	261	310	233
0	7	21	1	9	1	1	2	3	2	1	12	261	108	29	0
0	1	23	1	9	0	0	1	1	1	0	7	261	51	4	20
1	2	2	1	11	1	0	1	1	1	0	6	36	27	8	0
126	218	3	1	11	41	31	5	32	9	8	17	36	36	871	28
2	2	11	1	11	0	0	1	1	1	0	6	36	27	6	19
11	53	13	1	11	20	0	4	21	8	7	16	36	36	213	23
5	13	14	1	11	3	0	3	9	7	6	13	36	32	50	4
19	66	15	1	11	24	69	7	26	11	10	17	36	36	264	28
31	54	21	1	11	15	0	4	7	6	5	13	36	36	217	9
19	23	2	1	10	5	0	13	9	6	5	19	7	7	90	3
44	61	3	1	10	22	24	14	19	7	6	23	7	7	244	4
5	9	4	1	10	6	0	11	4	4	3	7	7	0	37	0
3	4	7	1	10	2	0	11	1	1	0	9	7	4	16	0
3	3	8	1	10	7	0	11	1	1	0	7	7	0	12	0
10	16	11	1	10	0	0	12	4	4	3	13	7	4	64	3
29	38	12	1	10	10	48	13	11	5	4	20	7	4	151	0
1	3	13	1	10	3	0	11	3	2	1	9	7	4	11	0
7	10	14	1	10	4	0	14	7	7	6	23	7	7	39	4
98	128	15	1	10	39	33	14	36	10	9	23	7	7	513	7
10	13	23	1	10	2	0	12	5	3	2	16	7	4	50	0
0	4	25	1	10	0	0	11	1	1	0	9	7	4	15	0

0	1	3	1	12	5	0	2	1	1	0	1	0	0	5	0
1	1	8	1	12	0	0	1	1	1	0	1	0	0	5	0
4	6	13	1	12	9	0	1	4	4	3	1	0	0	24	0
56	80	21	1	12	88	100	2	21	7	6	1	0	0	320	0
23	56	11	1	13	100	100	4	12	11	10	0	0	0	222	0
3	8	3	1	14	5	0	3	3	3	2	8	56	45	31	0
2	2	4	1	14	0	0	1	1	1	0	5	56	36	9	0
0	2	5	1	14	0	0	1	1	1	0	5	56	36	6	0
187	334	11	1	14	93	100	7	44	9	8	7	56	51	1338	56
2	2	14	1	14	0	0	1	1	1	0	5	56	36	8	0
2	2	15	1	14	0	0	1	1	1	0	5	56	36	8	0
1	1	21	1	14	0	0	1	1	1	0	2	56	9	3	13
25	36	22	1	14	3	0	3	6	4	3	2	56	20	142	13
38	82	3	1	15	57	50	5	4	3	2	5	22	4	328	0
38	70	7	1	15	43	50	2	15	4	3	3	22	4	278	22
1	1	11	1	15	0	0	1	1	1	0	2	22	4	3	4
31	31	22	1	15	0	0	3	3	1	0	2	22	18	122	18
2	3	28	1	15	0	0	1	1	1	0	1	22	0	12	0
59	118	5	1	16	82	100	3	8	4	3	3	23	23	470	23
4	12	10	1	16	15	0	1	2	2	1	3	23	23	48	0
2	2	14	1	16	0	0	1	1	1	0	3	23	23	8	5
1	3	15	1	16	4	0	1	1	1	0	3	23	23	10	5
0	12	3	1	17	17	0	1	3	3	2	3	7	3	48	3
1	2	5	1	17	1	0	1	1	1	0	0	7	0	8	0
98	139	8	1	17	40	0	2	13	7	6	3	7	7	554	4
23	57	10	1	17	42	0	1	7	4	3	3	7	3	227	7
43	47	21	1	17	0	0	2	2	1	0	3	7	3	186	3
2	4	3	1	18	5	0	2	2	2	1	3	8	0	17	0
79	120	8	1	18	75	0	3	12	4	3	2	8	8	478	8
0	1	10	1	18	2	0	1	1	1	0	1	8	0	4	0
0	3	25	1	18	6	0	1	1	1	9	2	8	0	10	0
32	39	30	1	18	11	0	1	5	5	4	0	8	0	154	0
4	5	7	1	19	100	0	2	1	1	0	0	0	0	20	0
36	46	3	1	20	100	0	4	10	6	5	1	0	0	184	0
9	9	15	1	20	0	0	1	2	2	1	1	0	0	35	0

15	16	8	1	21	100	0	1	1	1	0	0	0	0	65	0
42	60	3	1	22	85	100	5	11	5	4	2	20	16	238	20
1	2	4	1	22	4	0	1	1	1	0	1	20	0	6	0
3	5	9	1	22	6	0	1	3	3	2	0	20	4	20	20
0	1	28	1	22	6	0	1	1	1	0	1	20	0	4	0
0	1	4	1	23	1	0	1	1	1	0	2	27	12	4	0
105	195	9	1	23	81	53	5	36	6	5	7	27	27	779	27
10	20	11	1	23	11	0	2	7	6	5	2	27	0	78	0
0	2	13	1	23	2	0	1	1	1	0	3	27	12	8	0
2	4	15	1	23	0	47	2	3	2	1	5	27	24	17	0
28	39	27	1	23	4	0	1	4	3	2	2	27	12	155	0
844	1271	4	1	24	96	100	5	40	4	3	5	59	59	5084	59
1	2	11	1	24	0	0	1	2	2	1	4	59	50	9	0
1	3	15	1	24	0	0	2	2	2	1	5	59	59	12	9
0	1	21	1	24	0	0	1	1	1	0	0	59	0	5	0
4	14	23	1	24	3	0	1	7	4	3	4	59	50	57	5
0	3	25	1	24	1	0	1	1	1	0	4	59	50	11	0
1	1	4	1	25	0	0	1	1	1	0	1	57	0	3	4
0	1	21	1	25	0	0	1	1	1	0	2	57	48	4	0
224	480	23	1	25	98	100	4	36	5	4	3	57	57	1919	57
25	35	27	1	25	2	0	1	5	3	2	2	57	48	141	4
169	286	23	1	26	100	100	4	24	6	5	0	5	5	1145	5
2	2	15	1	27	0	0	1	1	1	0	1	0	0	8	0
14	31	23	1	27	100	0	1	4	2	1	1	0	0	122	0
8	9	4	1	28	3	0	3	4	4	3	1	23	0	35	0
0	2	13	1	28	5	0	2	2	2	1	3	23	23	9	0
93	123	25	1	28	53	0	1	6	1	0	2	23	19	492	19
14	32	26	1	28	38	0	2	6	2	1	2	23	19	129	9
9	12	31	1	28	0	0	2	3	1	0	2	23	4	46	4
16	21	2	1	29	29	0	1	3	2	1	3	0	0	85	0
6	8	3	1	29	14	0	2	2	2	1	2	0	0	33	0
37	39	4	1	29	5	0	3	10	4	3	7	0	0	154	0
0	1	9	1	29	0	0	1	1	1	0	4	0	0	4	0
1	1	10	1	29	0	0	1	1	1	0	3	0	0	4	0
1	1	14	1	29	0	0	2	2	2	1	7	0	0	6	0
26	38	15	1	29	52	0	6	14	8	7	10	0	0	150	0
1	1	23	1	29	0	0	1	1	1	0	4	0	0	3	0
2	2	7	1	30	0	0	1	1	1	0	2	0	0	7	0
2	2	14	1	30	0	0	1	1	1	0	2	0	0	8	0
7	8	15	1	30	100	0	2	2	2	1	2	0	0	31	0
0	2	2	1	31	16	0	1	1	1	0	2	28	4	9	5
42	54	3	1	31	55	0	3	10	4	3	5	28	4	214	19
4	4	11	1	31	0	0	1	2	2	1	1	28	0	16	0
6	10	13	1	31	7	0	3	3	2	1	6	28	11	40	11
6	8	14	1	31	0	29	4	6	5	4	6	28	17	37	8
21	34	15	1	31	14	71	8	10	5	4	12	28	28	137	23
27	29	21	1	31	9	0	3	9	8	7	4	28	13	114	13
0	1	2	1	32	13	0	1	1	1	0	1	0	0	4	0
0	5	3	1	32	50	0	1	2	2	1	1	0	0	19	0
9	11	11	1	32	16	0	2	3	3	2	2	0	0	42	0
0	1	13	1	32	9	0	1	1	1	0	1	0	0	3	0
0	1	22	1	32	13	0	1	1	1	0	1	0	0	4	0
1	20	2	1	33	100	0	2	1	1	0	2	0	0	81	0
1	1	13	1	33	0	0	1	1	1	0	2	0	0	4	0
4	5	15	1	33	0	0	1	2	2	1	2	0	0	23	0
2	7	21	2	8	100	100	3	3	3	2	0	0	0	28	0
377	707	2	2	9	98	81	4	36	12	11	2	68	60	2850	68
4	9	3	2	9	1	0	1	5	4	3	0	68	56	34	28
2	12	15	2	9	2	19	2	7	4	3	2	68	0	46	0
3	3	2	2	10	0	0	1	2	2	1	5	0	0	13	0

27	32	3	2	10	25	0	3	12	4	3	8	0	0	126	0
0	4	8	2	10	42	0	1	1	1	0	2	0	0	15	0
3	3	14	2	10	0	0	2	3	3	2	7	0	0	10	0
42	50	15	2	10	36	0	4	18	8	7	10	0	0	199	0
1	1	18	2	10	0	0	1	1	1	0	5	0	0	5	0
5	5	23	2	10	0	0	2	2	1	0	7	0	0	19	0
0	1	1	2	11	0	0	1	1	1	0	6	149	4	4	16
4	7	2	2	11	1	15	3	4	3	2	12	149	74	29	50
122	160	3	2	11	44	0	7	17	5	4	18	149	145	640	145
0	6	5	2	11	2	38	1	2	2	1	6	149	4	24	0
3	3	11	2	11	0	0	1	1	1	0	4	149	28	10	22
4	6	13	2	11	3	0	2	3	2	1	9	149	55	24	38
17	21	14	2	11	4	0	4	8	4	3	14	149	87	82	102
64	93	15	2	11	30	46	8	17	8	7	16	149	129	372	149
42	55	21	2	11	16	0	1	8	7	6	1	149	20	221	111
6	10	3	2	12	29	0	1	2	2	1	0	5	0	39	0
1	1	4	2	12	0	0	1	1	1	0	1	5	0	4	0
0	1	15	2	12	0	100	1	1	1	0	0	5	0	4	0
45	57	21	2	12	71	0	3	20	8	7	1	5	5	228	5
1	1	11	2	13	0	0	1	1	1	0	0	0	0	4	0
1	1	2	2	14	0	0	1	1	1	0	2	0	0	4	0
0	1	3	2	14	7	0	1	1	1	0	1	0	0	4	0
81	114	11	2	14	93	100	5	22	8	7	3	0	0	457	0
1	1	12	2	14	0	0	1	1	1	0	2	0	0	4	0
46	57	3	2	15	42	0	4	11	3	2	1	9	9	228	5
36	49	7	2	15	58	100	2	11	5	4	1	9	4	197	4
5	8	5	2	16	100	0	2	2	1	0	0	0	0	32	0
0	19	3	2	17	24	0	1	2	2	1	3	6	6	74	4
75	93	8	2	17	19	0	2	8	4	3	3	6	6	373	0
56	106	10	2	17	27	0	2	9	4	3	3	6	6	424	3
0	4	21	2	17	32	100	1	1	1	0	3	6	6	16	0
1	5	3	2	18	0	0	2	2	2	1	1	4	0	20	0
31	40	8	2	18	66	0	2	7	4	3	0	4	4	160	4
26	34	30	2	18	34	100	1	5	1	0	1	4	0	137	4
2	2	7	2	19	0	0	1	1	2	1	0	0	0	8	0
18	21	3	2	20	38	0	4	7	4	3	2	0	0	84	0
5	6	15	2	20	38	0	1	3	2	1	2	0	0	25	0
0	1	23	2	20	23	0	1	1	1	0	2	0	0	3	0
10	10	8	2	21	0	0	4	2	2	1	0	0	0	40	0
14	20	3	2	22	74	0	2	5	4	3	0	0	0	81	0
8	8	9	2	22	0	0	1	4	1	0	0	0	0	33	0
0	2	28	2	22	26	0	1	1	1	0	0	0	0	8	0
64	99	9	2	23	98	100	3	23	4	3	2	12	12	397	12
9	10	11	2	23	4	0	2	6	4	3	1	12	0	38	0
4	4	27	2	23	0	0	1	3	3	2	1	12	0	15	0
0	1	2	2	24	1	0	1	1	1	0	1	8	0	4	0
637	826	4	2	24	97	0	4	35	5	4	5	8	8	3329	8
0	1	9	2	24	0	0	1	1	1	0	4	8	8	3	0
0	2	11	2	24	1	100	1	2	2	1	4	8	8	10	0
0	1	15	2	24	1	0	1	1	1	0	4	8	8	5	0
4	4	4	2	25	0	0	1	3	2	1	3	10	6	15	0
1	1	8	2	25	0	0	1	2	2	1	3	10	6	6	0
189	258	23	2	25	100	100	4	25	3	2	4	10	10	1031	10
6	8	27	2	25	0	0	1	3	3	2	3	10	6	30	0
2	2	4	2	26	0	0	1	1	1	0	1	4	0	8	0
238	281	23	2	26	100	100	4	21	6	5	1	4	4	1123	4
6	6	23	2	27	100	0	1	2	1	0	0	0	0	23	0
4	4	4	2	28	0	0	2	3	3	2	0	2	0	17	0
23	26	26	2	28	100	0	1	6	4	3	0	2	2	104	2
8	10	2	2	29	18	0	1	3	3	2	4	4	0	41	0

4	4	3	2	29	0	0	2	2	2	1	9	4	0	17	0
11	14	4	2	29	23	100	3	8	5	4	7	4	4	55	4
1	2	9	2	29	0	0	2	2	2	1	9	4	0	9	0
1	1	10	2	29	0	0	1	1	1	0	4	4	0	4	0
1	2	14	2	29	18	0	2	2	2	1	9	4	0	8	0
30	38	15	2	29	41	0	4	17	8	7	11	4	0	152	0
1	2	23	2	29	0	0	2	2	2	1	7	4	0	7	0
5	5	15	2	30	0	0	1	1	1	0	0	0	0	19	0
1	1	2	2	31	0	0	1	1	1	0	0	0	0	5	0
1	1	21	2	31	0	0	1	1	1	0	0	0	0	4	0
7	11	2	2	32	44	0	1	2	1	0	0	28	12	43	24
2	5	3	2	32	0	24	2	2	2	1	6	28	0	19	0
8	8	8	2	32	0	0	1	1	1	0	0	28	0	32	0
14	23	11	2	32	0	77	3	7	5	4	5	28	4	90	0
1	1	14	2	32	0	0	1	1	1	0	3	28	0	3	8
12	13	15	2	32	0	0	4	3	3	2	7	28	3	50	12
21	21	21	2	32	0	0	3	1	1	0	5	28	16	84	16
5	9	22	2	32	56	0	1	1	1	0	3	28	0	37	0
2	5	3	3	8	0	15	1	2	2	1	1	5	5	18	5
4	4	15	3	8	0	0	1	1	1	0	1	5	0	16	0
37	53	21	3	8	0	85	1	14	7	6	2	5	5	212	0
293	474	2	3	9	78	20	5	25	5	4	11	42	30	1897	42
63	96	3	3	9	8	23	4	16	6	5	12	42	42	384	42
0	1	5	3	9	0	6	4	1	1	0	1	42	13	4	0
0	1	7	3	9	1	0	1	1	1	0	6	42	23	4	0
0	1	13	3	9	0	6	1	1	1	0	6	42	23	4	0
1	4	14	3	9	2	0	1	4	4	3	9	42	23	16	11
3	29	15	3	9	12	43	2	11	6	5	11	42	30	114	39
2	2	2	3	10	0	0	3	2	2	1	9	0	0	8	0
4	4	3	3	10	0	0	2	3	2	1	11	0	0	15	0
1	3	4	3	10	10	0	2	2	2	1	11	0	0	12	0
0	2	7	3	10	12	0	1	1	1	0	7	0	0	9	0
0	6	8	3	10	29	0	1	2	1	0	4	0	0	22	0
0	4	11	3	10	21	0	3	3	2	1	13	0	0	16	0
14	15	12	3	10	5	0	2	3	3	2	9	0	0	60	0
2	4	14	3	10	5	30	2	2	2	1	9	0	0	19	0
23	30	15	3	10	18	70	4	15	6	5	15	0	0	119	0
0	1	1	3	11	2	0	1	1	1	0	4	147	100	4	29
2	4	2	3	11	0	6	2	2	2	1	9	147	27	8	14
121	157	3	3	11	50	0	6	16	4	3	17	147	147	629	143
0	8	5	3	11	0	24	1	2	2	1	4	147	15	32	4
8	11	11	3	11	0	0	1	2	1	0	5	147	12	44	0
4	5	13	3	11	3	0	2	3	2	1	9	147	119	18	56
16	23	14	3	11	8	0	3	9	4	3	13	147	127	90	133
89	134	15	3	11	30	70	7	17	7	6	18	147	147	537	143
54	64	21	3	11	7	0	2	10	4	3	3	147	21	256	107
1	1	4	3	12	0	0	1	1	1	0	1	0	0	4	0
0	1	14	3	12	100	0	1	1	1	0	1	0	0	5	0
46	48	21	3	12	0	0	2	13	5	4	2	0	0	190	0
14	20	3	3	13	2	9	2	6	5	4	3	57	41	80	0
0	2	7	3	13	4	0	1	1	1	0	1	57	0	8	0
289	373	11	3	13	92	91	7	36	14	13	4	57	57	1492	57
0	2	21	3	13	2	0	1	1	1	0	2	57	41	8	24
6	7	3	3	14	0	0	2	3	2	1	1	4	4	29	4
0	2	7	3	14	0	0	1	1	1	0	1	4	0	6	0
207	292	11	3	14	100	100	5	32	9	8	2	4	4	1169	4
44	70	3	3	15	38	100	5	13	7	6	2	19	19	279	3
48	84	7	3	15	62	0	2	11	4	3	2	19	19	334	19
8	8	5	3	16	0	0	2	1	1	0	0	0	0	31	0
0	1	11	3	16	100	0	1	1	1	0	0	0	0	4	0

146	181	8	3	17	100	0	3	18	2	1	2	8	8	724	8
2	2	11	3	17	0	0	1	1	1	0	2	8	8	8	0
1	1	15	3	17	0	0	1	1	1	0	2	8	8	4	0
2	2	3	3	18	0	0	1	1	1	0	1	0	0	8	0
43	61	8	3	18	100	0	2	10	5	4	1	0	0	244	0
1	1	10	3	18	0	0	1	1	1	0	0	0	0	4	0
41	44	3	3	20	100	0	3	8	6	5	2	0	0	177	0
9	9	15	3	20	0	0	2	3	2	1	2	0	0	37	0
15	16	8	3	21	0	0	2	3	3	2	0	0	0	63	0
37	55	3	3	22	83	0	4	9	7	6	3	0	0	103	0
2	4	9	3	22	12	0	2	2	2	1	1	0	0	16	0
0	1	15	3	22	4	0	1	1	1	0	1	0	0	3	0
2	2	28	3	22	0	0	1	1	1	0	2	0	0	8	0
17	21	9	3	23	9	57	3	11	7	6	6	8	8	84	8
36	56	11	3	23	84	43	2	13	7	6	1	8	0	224	8
0	2	14	3	23	0	0	1	1	1	0	3	8	8	8	8
1	3	15	3	23	0	0	2	2	2	1	3	8	8	10	8
0	1	27	3	23	6	0	1	1	1	0	3	8	8	5	0
2	2	3	3	24	0	0	1	1	1	0	2	7	7	8	0
402	521	4	3	24	100	0	4	21	3	2	2	7	7	2094	7
1	1	23	3	24	0	0	1	1	1	0	2	7	7	4	0
28	35	23	3	25	100	0	3	10	5	4	0	3	3	140	0
37	51	23	3	26	100	0	3	9	5	4	0	0	0	202	0
4	4	4	3	28	0	0	1	2	1	0	0	0	0	16	0
23	36	26	3	28	100	0	1	8	1	0	0	0	0	145	0
6	6	31	3	28	0	0	1	1	1	0	0	0	0	24	0
4	4	3	3	29	0	0	2	2	2	1	3	4	4	15	0
2	2	5	3	29	0	0	1	2	2	1	1	4	0	9	0
15	18	15	3	29	100	0	4	7	6	5	4	4	4	72	4
1	1	21	3	29	0	0	1	1	1	0	2	4	4	4	0
1	1	3	3	30	0	0	1	1	1	0	1	0	0	3	0
9	11	15	3	30	100	0	2	3	3	2	1	0	0	45	0

NOTE:
number of cases = 325
TT= Trade type to be transformed to x14 during analysis
EC= elemental classification to be transformed to x4 during during analysis
FL=Floor level to be transformed to x19 during analysis
number at the top of table refers to variables to number
5A, 5B and 5C = to be chosen for x5 during analysis
NV and TH are not variables

ROW SELECTION NUMBER 4 STAGE
COLUMN SELECTION NUMBER 6 TECHNIQUE

APPENDIX D.1

TABLE T1 - ELEMENT V. ACTIVITY

CLASS CODE	STAGE	TECHNIQUE O	E1	H1	P1	T1	U1	H2	OMR CODES T2	A	I	RK	CL	N	RO	(iii) TECHNIQUE RT	SU	W	TOTAL (F)
0			33	1311	635	88	97	285		8734	1886	430	207	21	2392		313	4297	20728
ST1	EXTERNAL WORKS		2526	825	272	318	16	175					34	228	4	28	433		4858
ST2	TEMPORARY SERVICES		26	132	24			8						4			7		201
ST3	DRAINAGE		1576	112	54	59	4	161	119				23	81		108	112		2409
ST4	OVERSITE EXCAVATION		24														8		32
ST5	PILING		808	87	112	91		16	12				32	8		65	176		1406
ST6	FOUNDATIONS		4175	494	971	494		276					298	111		110	903		7831
ST7	GROUND FLOOR SLAB		1840	20	113	99	8	242					60	168		153	201		2904
ST8	STEELWORK		1027	36	139	62	34	56						56		118	116		1643
ST9	BRICKWORK BLOCKWOR	(i)	4270	45	1057	184	64	1415					84	724		346	252 (iv)		(ii) 8439
ST10	SCAFFOLDING		912	4	14		5	231					10	45		21	7		1249
ST11	UPPER FLOOR SLABS		772		136	4	151	287					41	196		39	39		1664
ST12	STAIRS & LANDINGS		246		41	5	11	37						10		4			353
ST13	ROOF COVERING AND FI		91	20	8		39	52					0	8		4			222
ST14	WALL CLADDING		886		226	27	14	136					7	156		98	60		1600
ST15	DOOR & WINDOW DETAIL		439		104	22	22	110						50		8	10		763
ST16	FLOOR FINISHES		266		48			66					13	96		51	19		559
ST17	WALL FINISHES		659		142	48		66					24	85			7		1030
ST18	CEILING FINISHES		449		93		8	28					46	39			8		671
ST19	GLAZING		17					3											20
ST20	JOINERWORK		177		15	23								4					219
ST21	PAINTING & DECORATIN		60		6														65
ST22	FIXTURES & FITTINGS		182		47	13		12						12		4	20		289
ST23	PLUMBING		575		177	10		86	59				8	105		19	27		1067
ST24	ELECTRICAL		3398	4	733	151	24	311	23				35	473		5	82		5236
ST25	HEATING		999	4	652	30	37	210						110		26	57		2124
ST26	VENTILATION & AIR CO		675		144	12		108	16				28	154		8	5		1150
ST27	GAS		64		36	4		7						19					130
ST28	SPECIALIST SERVICES		492		86	13		83					4	43			14		733
ST29	SERVICES BUILDERWORK		351		38			12					8	29					438
ST30	CLEANING & RECTIFYIN		41		4														45
ST31	MATERIALS STORE		426		13	43		9					9	68		17	12		595
ST32	LINKWAY		37		24			8						4					72

NOTES:
THEORETICAL MODEL C
All data shown in example from ground floor output
(i) Productive man-hours for brickwork
(ii) Total man-hours for brickwork (deduct SU activity)
(iii) Variable X7
(iv) Variable X5B = 252-(76+4)[from table T7)=172

PAGE SELECTION NUMBER 4 STAGE

ROW SELECTION NUMBER 5 OPERATION
COLUMN SELECTION NUMBER 6 TECHNIQUE

APPENDIX D.2
TABLE T2 - ELEMENT/OPERATION V. ACTIVITY

OMR CODE	TECHNIQUE O	F1	H1	P1	T1	U1	H2	T2	OMR CODES A	I	BK	CL	N	RO	(iii) RT	(iv) SU	TOTAL
0													4				4
A		(i) 1687	37	410	62	16	520					29	203		158	139	(ii)→ 3261
B		1717		481	79	32	739					55	434		173	75	3786
C		336		86			64						61			10	556
D		412	8	28	43	16	91						18		11	29	655
E		118		51									5		4		178
F																	0
G																	0
H																	0
I																	0
J																	0
K																	0
TOTAL	0	4270	45	1057	184	64	1415	0	0	0	0	84	724	0	346	252	8439

NOTES:
THEORETICAL MODEL D
All data shown in example from ground floor output
Element brickwork shown to be transformed to variable X4
(i) Productive man-hours for operation 9(a)
(ii) Total man-hours (deduct SU)
(iii) Variable X7
(iv) Variable X5B

ROW SELECTION NUMBER 11 TRADE
COLUMN SELECTION NUMBER 6 TECHNIQUE

APPENDIX D.3
TABLE T3 - TRADE V. ACTIVITY

CODE	TRADE (v)	TECHNIQUE O	FI	HI	PI	TI	UI	H2	T2	OMR CODES A	F	BK	CL	N	(iv) RO	(iii) RT	TECHNIQUE SU	W	TOTAL
ASP	ASPHALTER		148		1	4				36			17	20		4	10		240
BRI	BRICKLAYER	(i)	4788	90	1069	123	37	1404		1118	241	40	88	741	1232	297	85	233	(ii) 11584
CAR	CARPENTER		4999	428	1395	210	98	482	18	921	277	5	57	307	191	75	55	550	10065
ELE	ELECTRICIAN		3614	4	727	144	34	309	23	1251	115	72	35	472			32	781	7613
FLO	FLOORLAYER		243		42			48		237	40		13	87	12	63		12	796
GLAZ	GLAZIER		186		58	7	7	41		146	22	16		21		4		63	571
PAI	PAINTER		822	8	143			56		499	71	11	53	83				183	1929
PLUM	PLUMBER		435	16	149	10	3	55	59	358	136	5	8	82		10	4	126	1455
PLAS	PLASTERER		102		76			20		90	4	11	17	29				16	365
RAC	ROOFER AND CLADDER		986	104	265	37	65	239		693	239	136	42	130	592	111	4	186	3828
SCA	SCAFFOLDER		118	4				23		118					15	10			288
DVRS	PLANT DRIVERS		1494	545	45	5	86	340		307	35		242	264	49	36		26	3473
ENG	ENGINEERS		29	5	12	668		3		3					28	4	912	140	1804
OFF	OFFICE STAFF		28	3		254		4	4	43	18				8	9	1632	266	2259
GAN	GANGERS		709	302	73	27	18	139	20	344	80		40	47	30	23	141	310	2304
GENL	GENERAL LABOURERS		4137	1304	581	205	97	657	77	877	369		301	281	143	352		519	9901
SELE	ELECTRICITY BOARD		4	24	12														40
PUE	PO ENG.			12	4						4							4	24
SFE	STEEL FIXER AND EREC		2609	74	505	52	41	168		508	71	57	8	147	58	137		209	4643
WIR	WROUGHT IRON WORKER		220		8	3		4		64				33	15			9	355
HER	HEATING ENGINEERS		1687	8	833	49	37	357	16	750	110	74	28	279		34		543	4804
PLG	PILING		359	49	53			29	12	41	36		32	9	23	61	20	16	738
SAT	SOUND ATTENUATORS		370		65			49		16		5		44				34	583
LIE	LIFT INSTALLER		56		30	3		35		49				4				33	212
INS	INSULATORS		209		24			11		102	19	0	4	53				27	447
VDE	VESTIBULE DOOR FIXER		9					4		40				3				8	64
GRD	GARDENERS		16	114	11	3				16									160
PLE	PUBLIC LIGHTING ENGI		36							18				10					64
CEIT	CEILING FITTER		126				8	12		89				8				4	247
TOTAL:		0	28538	3093	6178	1801	532	4490	228	8734	1886	430	986	3152	2396	1229	2886	4297	70855

NOTES:
THEORETICAL MODEL B
All data shown in example from ground floor output
(i) Productive man-hours for bricklayer
(ii) Total man-hours for bricklayer
(iii) Variable X7
(iv) Variable X18
(v) Trade types to be transformed to X14

PAGE SELECTION NUMBER 4 STAGE

ROW SELECTION NUMBER 5 OPERATION

COLUMN SELECTION NUMBER 11 TRADE

APPENDIX D.4

TABLE T4 – STAGE/OPERATION V. TRADE

(iii)

OMR CODE	TRADE 0	ASP	BRI	CAR	ELE	I RAC	SCA	DVRS	ENG	OFF	GAN	GENL	SFE	WIR	HER	TOTAL
0			4													4
A			3046	1		5		18	43	105	8	36				3261
B			(i) 3401	26	15			56	8	43	32	176	26		4	3786
(iv) C			547							5		4				556
D			412	65				21	37	20	12	85	3			655
E			4	160							5	9				178
F																0
G																0
H																0
I																0
J																0
K			(vi)						(ii)							0
TOTAL	0	0	7415	251	15	5	0	94	88	173	57	310	29	0	4	8439 (v)

NOTES:
All data shown in example from ground floor output
(i) THEORETICAL MODEL B
Variable X1
Trade bricklayer = 6 operations in element Brickwork. Add this with other elements undertaken for ground floor.
(ii) THEORETICAL MODEL C
Variable X5B
(iii) THEORETICAL MODEL C
Variable X12A for element brickwork
(iv) THEORETICAL MODEL C
Variable X1 for element brickwork
(v) THEORETICAL MODEL C
Variable X12B for element brickwork
= 8439-261
= 8178/9
= 908.67
= trade with hours > 908.67 is bricklayer
therefore variable X12B for brickwork is 1
(vi) THEORETICAL MODEL C
VARIABLE X14 =Main trade type employed
= Bricklayer for brickwork = trade within control main contractor

PAGE SELECTION NUMBER 4 STAGE

ROW SELECTION NUMBER 11 TRADE
COLUMN SELECTION NUMBER 6 TECHNIQUE

APPENDIX D.5
TABLE T7 - STAGE/TRADE V. ACTIVITY

(iii) :TECHNIQUE CODE	0	F1	H1	P1	T1	U1	H2	T2	A	I	BK	CL	N	RO	RT	SU	TOTAL (vi)
								OMR CODES									
BRI		4049	36	925	92	12	1234					53	673	(iv)	265	76	7415
CAR		156		70	5	4						10	5		1		251
ELE		8											8				15
RAC															5		5
DVRS						20	62						8		4		94
ENG (i)					40											48	88
OFF					44										5	124	173
GAN		9				5	31						9			4	57
GENL		49	9	58	3	24	62					21	23		63		310
SFE				4			22								3		29
HER		(ii)					4										4
TOTAL	0	4270	45	1057	184	64	1415	0	0	0	0	84	724	0	346	252	8439 (v)

NOTES:
All data shown in example from ground floor output
THEORETICAL MODEL E
(i) The management team
(ii) Productive hours
(iii) Gangs and transformed to X14
(iv) variable X7
= 265-5 =261/341 = 78%
(v) Variable X13 7339/8439
= 85%
(vi) Total hours
= 7415-76
= 7339

ROW SELECTION NUMBER 1 DATE
COLUMN SELECTION NUMBER 6 TECHNIQUE

APPENDIX D.6

TABLE T8 - DATE V. ACTIVITY

	TECHNIQUE							OMR CODES					(iv)	(iii)	(i)		TOTAL
SETS	O	F1	H1	P1	T1	U1	H2	T2	A	I	BK	CL	N	RO	RT	SU	W	(v)
0		(ii)	509	2436	326	120	1722	195	4992	882	246	360	1450	119	428	453	2818	27980
WK 1			89	3	8											20		120
WK 2		24	168	4	72	8										44	8	328
WK 3		24	169	12	56									16		84	4	364
WK 4		88	160	8	56		32			4						40	36	424
WK 5		243	179	55	67				16				52			84	24	720
WK 6		280	84	36	60		4	12	4			32	16	28		76		632
WK 7		214	80	78	62		4					4	5	52		70	12	581
WK 8		393	36	36	76		11		4			8	8			108	20	700
WK 9		440	28	124	40		4		28	4		4	16			100	24	812
WK10		392	60	124	24		12		32		12		12	72	8	88	8	844
WK11		460	67	81	40	4	40		24		4			52		80	12	864
WK12		504	124	60	44		52		36						4	100	4	928
WK13		375	38	78	49		4		8				21			89	22	685
WK14		338	79	48	40		39		68	32			11	107	69	52	53	935
WK15		670	76	142	41	16	40		56		11		13		32	115	35	1246
WK16		664	80	56	64		80		16			24	4	92	28	92	20	1220
WK17		991	40	115	69		90		12			72	2			126	14	1532
WK18		1050	38	97	28	16	79		28			82	12		44	128	15	1616
WK19		949	44	118	38	15	112		19		16	84	7		24	119	29	1574
WK20		728	132	120	28	28	48		44	12		40	20		56	128	8	1392
WK21		268	24	60	8		16		36				8	28		40		488
WK22		560	33	100	37		108	21	106			35	27		26	25	8	1084
WK23		538	4	68	28	27	145		78			12	12		31	35		977
WK24		449		110	14	54	113		107	8		28	20	83	28	36		1048
WK25		300	10	83	27		76		80	77	17		39	248	3	8	7	974
WK26		348	37	125	16	63	68		60	23	25		66	18	20	32	39	939
WK27		239	11	67	9	11	57		154	24		9	14		27		20	643
WK28																		0
WK29																		0
WK30		144	30	77	14	3	47		95	23		5	27	168	18	6	25	680
WK31		376	56	94	34	4	98		98	23			57	107	25	40	8	1021
WK32		343	33	79	4	12	103		77	45			72	108	77	36		987

NOTES:
All data shown in example from ground floor output
THEORETICAL MODEL A
(i) Variable X5A
(ii) Productive hours
(iii) variable X7
(iv) Variable X18
(v) Total hours deduct variable X5B

APPENDIX D.7
TABLE T10 - DATE V. TRADE

ROW SELECTION NUMBER 1 DAT
COLUMN SELECTION NUMBER 11 TRA

SETS	TRADE 0	ASP	BRI	CAR	PLUM	PLAS	RAC	SCA	DVRS	(iii) ENG	OFF	GAN	GENL	SELE	POE	STV	SFE	WIR	HER	PLG	TOTAL
0		240	2674	3023	1115	365	1092	16	547	168	640	781	2577				1314	168	4068	86	27980
WK 1									24		24	24	48								120
WK 2									104	40	48	24	112								328
WK 3									40	80	48	8	72							60	364
WK 4			24	64	20				40	60	24		60		16	(iv)			(v)	116	424
WK 5			4	80					116	80	56	40	72	24	8					160	720
WK 6				56					120	60	36	40	112	4						176	632
WK 7				80					96	80	45	40	208				32				581
WK 8				96					84	84	88	40	160	4			144				700
WK 9				88					120	84	72	56	256				136				812
WK10				264					80	60	44	48	208				120				844
WK11			64	264					88	72	48	40	200				88				864
WK12			72	264					86	76	60	48	216				104				928
WK13				256					72	59	78	36	128				56				685
WK14				384					40	44	63	40	160				64			140	935
WK15	(ii)			416					80	88	51	48	296	4			264				1246
WK16				408					88	76	56	48	288				256				1220
WK17			176	392					152	64	98	48	280	4			328				1532
WK18			168	416					168	37	84	48	304				352				1616
WK19		(i)	312	304			63	12	120	32	107	40	296				288				1574
WK20			288	296			112	24	48	56	88	32	248				200				1392
WK21			96	112			12	24	32	12	28	16	96				56		4		488
WK22			317	240			78		72	32	17	40	248				50				1084
WK23			288	184			99	24	80	27	12	36	196				32				977
WK24			392	168			116	24	74	30	16	38	200								1048
WK25			392	123			166	16	61	12	13	40	140				8				974
WK26			364	112			149	24	64	11	24	40	142				10				939
WK27			299	51			82		80			16	98				18				643
WK28																					0
WK29																					0
WK30			367	59			102		44			23	76				10				680
WK31			445	100			138	24	57	24	21	29	133				32				1021
WK32			427	124			108		64	16	20	24	164				40				987

NOTES:
All data shown in example from ground floor output
(i) THEORETICAL MODEL B
Variable x15 for Bricklayer
- count number of weeks
(ii) THEORETICAL MODEL B
Variable X8 for bricklayer
- count the number of 'breaks' in manhour recorded
(iii) THEORETICAL MODEL A
Variable X5B
(iv) THEORETICAL MODEL A
Variable X12A
- count the number of trade types O
Variable X12B
- Determine cutoff point then count the num.
trade types mainly employed
(v) THEORETICAL MODEL A
Variable X14
- Find the trade in each week which has most
man-hours and then determine classification X

APPENDIX D.8
TABLE T12 - ELEMENT/DATE V. OPERATION

PAGE SELECTION NUMBER 4 STAGE

ROW SELECTION NUMBER 1 DATE
COLUMN SELECTION NUMBER 5 OPERATION

	SETS	OPERATION 0	A	B	C	D	E	F	G	H	I	J	K	TOTAL
							OMR CODES							
3	WK33		122	245	50									416
3	WK34		99	96		3		(iii)						198
2	WK35		68	13										81
3	WK36		22	124	24									171
3	WK37		4	132	23									159
3	WK38		40	163	34									237
3	WK39		33	120	63									210
3	WK40		115	55	21									191
2	WK41	(ii)	100	55										155
	WK42													(v) 0
4	WK43	4	105	80	4									193
3	WK44		24	20	16									60
2	WK45		101	29										131
3	WK46		96	16	9									121
2	WK47	(i)	14	32										46
4	WK48		124	23	6	3								156
4	WK49		113	5	20	4								141
3	WK50		180	13	23									215
	TOTAL	4	3261	3786	556	655	178	0	0	0	0	0	0	8439

(iv)

NOTES:
All data shown in example from ground floor output
(i) THEORETICAL MODEL D
Variable x3 for operation 9/A
- count number of weeks
(ii) THEORETICAL MODEL B
Variable X6 for operation 9/A
- count the number of 'breaks' in manhour recorded
(iii) THEORETICAL MODEL A
Variable X1
- count the number of operation for each week O
for all operations
(iv) THEORETICAL MODEL C
Variable X3
- count the number weeks for element brickwork
(v) THEORETICAL MODEL C
Variable X6
- count the number of 'breaks' for element
brickwork

PAGE SELECTION NUMBER 4 STAGE

ROW SELECTION NUMBER 1 DATE

COLUMN SELECTION NUMBER 11 TRADE

APPENDIX D.9

TABLE T14 - ELEMENT/DATE V. TRADE

SETS	:TRADE 0	ASP	BRI	CAR	ELE	SCA	DVRS	ENG	OFT	GAN	GENL	SELE	SFE	GRD	TOTAL
0		204	324	62		4	336	8	74	120	428		216		1771
WK 1							24		24	24	48				120
WK 2							76	36	[illegible]	24	112				264
WK 3							33	48	40	8	52			56	237
WK 4				(i) 64			36	4	20		28				152
WK 5				64			48	12	12	12	32	8		64	252
WK 6				28			80	28	28	32	80			8	284
WK 7				25			8	23	2		52		32		141
WK 8				60			12	48	32	12	72		132		368
WK 9				72			4	16	12	8	20		24		156
WK10				88				28	8	4	8				136
WK11				90				8	12		24		43		177
WK12				120				4	24	8	28				184
WK13				25					11	5	20		2		61
WK14				69			4	4		6	12				[illegible]
WK15										5	12				17
WK16				96						4	8		12		120
WK17				24							12				36
WK18															0
WK19			(ii) 64			(iv)		4							68
WK20															0
WK21				(iii)										2	0
WK22							3		5		11				19
WK23			36				4								40
WK24													3		0
WK25															0
WK26			15												15
WK27															0
WK28															0
WK29															0
WK30															0
WK31														16	16
WK32				4			12	8			16				40

NOTES:

All data shown in example from ground floor output

(i) THEORETICAL MODEL A
Variable X9
trade carpenter introduced in week 4
repeat for each week for all elements

(ii) THEORETICAL MODEL E
Variable X15
- count the number weeks for gang BRI for external works

(iii) THEORETICAL MODEL E
Variable X8
- count the number 'breaks' for gang BRI for external works

(iv) THEORETICAL MODEL E
Variable X5C
note quantity for MW when trade BRI coded for this element - 4 hours. Totalling this when another record appear gove X5C for GANG BRI - 53

APPENDIX E.1
THEORETICAL MODEL A
MODEL CHECKING AND SPECIFICATION
VARIABLE (QUANTITATIVE) SUMMARY

Ident	Min	Mean	Maximum	Values	Missing	
PH	0.0	254.1	1050.0	188	0	Skew
PT	20.0	545.7	1616.0	188	0	
X18	0.00	13.88	280.00	188	0	Skew
X5A	0.00	19.11	128.00	188	0	Skew
WK	1.00	47.07	82.00	188	0	
X16	1.000	2.468	4.000	188	0	
X12A	1.000	7.527	15.000	188	0	
X12B	1.000	2.878	7.000	188	0	
TS	9.00	66.04	230.00	188	0	
X5B	0.00	26.74	172.00	188	0	Skew
X1	1.00	12.60	29.00	188	0	
X17	1.000	2.723	9.000	188	0	Skew
X7	0.00	11.77	77.00	188	0	Skew

NOTE: SKEW = signs of non normality in identifier PH, x18, x5A, X5B, X7, X17

TRANSFORMING REMAINING VARIABLES X19, X9, X14 AND NT AND NP WERE DONE BY GENSTAT COMMAND AS FOLLOWS

```
FACTOR [LEVELS=!(1,2)]X19
FACTOR [LEVELS=!(0,1)]X9
FACTOR [LEVELS=!(1,2)]X14
CALCULATE X19=NEWLEVEL(FL;!(1,2,2))
& X9=NEWLEVEL(TN;!(0,1))
& X14=NEWLEVEL(MTT;!(2,2,1,2,2,1,1,2,2,1,2))
& TT=PT-MH
& NT=ROUND(TT/4)
& NP=ROUND(PH/4)
```

```
***** Regression Analysis *****
  Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant, X16,X17,X18,X19,X1,X7,
                   X5,X12B,X14,X9

*** Summary of analysis ***
    Dispersion parameter is 1

              d.f.    deviance    mean deviance
Regression     10       1601.       160.125
Residual      177       1152.         6.508
Total         187       2753.        14.723

Change        -10      -1601.       160.125

*** Estimates of regression coefficients ***

                  estimate        s.e.          t
Constant           -0.2917      0.0802      -3.64
X18              -0.003028    0.000351      -8.62
X5                0.009821    0.000522      18.82
X16                -0.0669      0.0144      -4.64
X19 2.00            0.9996      0.0480      20.82
X9  1              -0.0795      0.0341      -2.33
X14 2.00           -0.1204      0.0359      -3.35
X12B               -0.1016      0.0159      -6.38
X1                 0.02291     0.00384       5.96
X17                0.00016     0.00811       0.02
X7               -0.002735    0.000867      -3.15
* MESSAGE: s.e.s are based on dispersion parameter with
value 1
```

UNITS WITH HIGH LEVERAGE,RESIDUALS AND COOK'S DISTANCE

NUMBER	RRAW	LEV	R	COOKD
5.00	-13.16	0.11422	-4.317	0.24029
6.00	0.67	0.09470	-3.936	0.16208
14.00	-8.54	0.15801	-2.606	0.12746
15.00	1.10	0.10134	-2.573	0.07465
17.00	18.49	0.20380	-2.428	0.15086
18.00	53.98	0.22156	-2.423	0.16712
19.00	19.48	0.15236	-2.421	0.10535
20.00	-1.49	0.19398	-2.399	0.13853
21.00	27.10	0.04238	-2.219	0.02179
24.00	2.34	0.20203	-2.087	0.11031
25.00	23.44	0.21793	-1.951	0.10603
32.00	10.34	0.31553	-1.643	0.12449

33.00	-4.31	0.17813	-1.639	0.05826
40.00	-45.91	0.15415	-1.475	0.03964
41.00	-22.00	0.06601	-1.431	0.01446
51.00	34.13	0.10985	-1.065	0.01400
69.00	-44.43	0.05167	-0.516	0.00145
91.00	-35.76	0.05748	0.053	0.00002
101.00	-11.08	0.02879	0.179	0.00010
112.00	-18.39	0.03306	0.608	0.00126
121.00	17.81	0.02217	0.794	0.00143
154.00	-19.25	0.03794	1.626	0.01043
156.00	21.22	0.05257	1.644	0.01499
160.00	-1.72	0.01068	1.727	0.00322
161.00	8.82	0.00937	1.752	0.00290
183.00	24.66	0.02750	3.168	0.02838
185.00	21.37	0.05083	3.757	0.07557
188.00	-6.77	0.04792	5.375	0.14540

APPENDIX E.2
THEORETICAL MODEL B
MODEL CHECKING AND SPECIFICATION
VARIABLE (QUANTITATIVE) SUMMARY

Iden	Minimum	Mean	Maximum	Values	Missing	
PH	0.0	701.5	4999.0	68	0	Skew
PT	4	1434	11584	68	0	Skew
X18	0.00	39.13	1323.00	68	0	Skew
X7	0.00	32.16	352.00	68	0	Skew
X15	1.00	20.72	76.00	68	0	
X8	0.000	3.926	13.000	68	0	
X1	1.00	11.07	82.00	68	0	Skew
SWH	0.0	317.2	3222.0	68	0	Skew

TRANSFORMING REMAINING VARIABLES X19, X14

```
FACTOR [LEVELS=!(1,2)]X19
 FACTOR [LEVELS=!(1,2)]X14
 CALCULATE X14=NEWLEVEL(TT;!(2,2,2,1,2,2,2,2,2,
 1,1,2,2,2,1,1,1,\
 1,2,1,1,2,1,1,1,2,1,1))
 & NT=ABS(PT/4)
 & NP=ABS(PH/4)
 & X19=NEWLEVEL(FL;!(1,2,2))
 & X13=(PT/TOTAL(PT))*100
```

MODEL SPECIFICATION

```
***** Regression Analysis *****

 Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant, X14, X19, X7, X1, X8,
                   X18, X13


*** Summary of analysis ***
    Dispersion parameter is 1

              d.f.     deviance    mean deviance
Regression       7       1036.5        148.07
Residual        60        627.7         10.46
Total           67       1664.2         24.84

Change          -7      -1036.5        148.07


*** Estimates of regression coefficients ***

                  estimate          s.e.            t
Constant           -0.3458        0.0510        -6.78
X13                0.03897       0.00817         4.77
X14 2.00           -0.2781        0.0358        -7.76
X19 2.00            1.0187        0.0373        27.29
X7               -0.000678      0.000181        -3.74
X1                 0.00388       0.00119         3.25
X8                -0.01892       0.00597        -3.17
X18             -0.0000542     0.0000689        -0.79
* MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

UNITS WITH HIGH LEVERAGE, RESIDUALS AND COOK'S DISTANCE

NUMBER	RRAW	LEV	R	COOKD
1.00	16.43	0.0323	-9.570	0.436
2.00	61.69	0.9560	-5.377	89.813
3.00	38.99	0.7155	-4.723	8.013
4.00	-36.43	0.6171	-4.406	4.470
10.00	-149.77	0.4413	-1.909	0.411
13.00	-43.96	0.2045	-1.629	0.097
14.00	-48.86	0.8653	-1.566	2.250
16.00	162.11	0.3949	-1.228	0.141
17.00	24.74	0.0346	-1.167	0.007
18.00	-113.82	0.2294	-1.146	0.056
24.00	-9.71	0.0215	-0.830	0.002

28.00	-71.44	0.3548	-0.475	0.018
33.00	23.63	0.0440	-0.045	0.000
55.00	30.16	0.0745	1.821	0.038
58.00	30.73	0.3035	2.062	0.265
62.00	-61.27	0.0804	2.725	0.093
63.00	28.22	0.0437	3.105	0.063

APPENDIX E.3
THEORETICAL MODEL C
MODEL CHECKING AND SPECIFICATION
VARIABLE (QUANTITATIVE SUMMARY

Ident	Minimum	Mean	Maximum	Values	Missing	
PH	4.0	603.6	4270.0	79	0	Skew
PT	4.0	976.6	8439.0	79	0	Skew
X7	0.00	27.92	346.00	79	0	Skew
X12A	1.000	4.089	12.000	79	0	
X12B	1.000	1.519	5.000	79	0	Skew
X5B	0.00	48.62	1224.00	79	0	Skew
X5A	0.00	34.94	801.00	79	0	Skew
X3	1.00	17.81	53.00	79	0	
X6	0.000	4.633	12.000	79	0	
X1	1.000	4.405	11.000	79	0	

TRANSFORMING RAMIANING VARIABLES X14, X4, X19, X10

```
FACTOR [LEVELS=!(1,2)]X14
FACTOR [LEVELS=!(1,2)]X4
FACTOR [LEVELS=!(1,2)]X19
FACTOR [LEVELS=!(0,1)]X10
CALCULATE X19=NEWLEVEL(FL;!(1,2,2))
& X4=NEWLEVEL(EC;!(1,1,1,1,2,2,2,2,2,2,2,2,2,
2,2,1,1,\
1,1,1,1,1,2,2,2,2,2,2,2,1,1,1,1))
& X14=NEWLEVEL(MTT;!(2,2,2,1,2,2,2,2,2,1,1,2,
2,2,1,1,1,\
1,2,1,1,2,1,1,1,2,1,1))
& X10=NEWLEVEL(DT;!(0,0,1,1,0))
& TT=PT-X5B
& NT=ROUND(TT/4)
& NP=ROUND(PH/4)
& X2=(TT/TOTAL(TT))*100
```

MODEL SPECIFICATION

***** Regression Analysis *****

```
 Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant, X4, X12A, X3, X5B, X14,
                   X19, X10, X7, X1, X6, X2, X12B
```

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	12	449.1	37.425
Residual	66	416.6	6.312
Total	78	865.7	11.099
Change	-12	-449.1	37.425

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6617	0.0838	7.90
X4 2.00	0.0095	0.0582	0.16
X12A	0.0246	0.0122	2.02
X3	-0.01485	0.00319	-4.65
X5B	-0.000212	0.000112	-1.89
X14 2.00	-0.1777	0.0495	-3.59
X19 2.00	0.5381	0.0453	11.89
X10 1	-0.4153	0.0502	-8.28
X7	0.000460	0.000345	1.33
X1	0.0327	0.0121	2.70
X6	0.0331	0.0101	3.27
X2	0.0096	0.0141	0.68
X12B	-0.0318	0.0278	-1.14

* MESSAGE: s.e.s are based on dispersion parameter with value 1

UNITS WITH HIGH LEVERAGE, RESIDUALS AND COOK'S DISTANCE

NUMBER	RRAW	LEV	R	COOKD
1.00	-31.650	0.8111	-5.657	11.4508
2.00	-26.631	0.0454	-5.106	0.1035
3.00	51.691	0.4494	-4.173	1.1845
5.00	-2.333	0.4133	-3.133	0.5761
6.00	12.643	0.9658	-3.045	21.8369
7.00	-1.071	0.5776	-2.369	0.6394

9.00	-15.301	0.9279	-1.971	4.1667
10.00	41.747	0.4920	-1.785	0.2572
11.00	-17.244	0.3580	-1.661	0.1282
14.00	-7.221	0.3525	-1.557	0.1100
24.00	38.096	0.7168	-0.619	0.0808
25.00	-70.993	0.2315	-0.548	0.0075
33.00	-11.112	0.0290	-0.097	0.0000
35.00	4.124	0.4319	-0.059	0.0002
43.00	-37.686	0.1082	0.466	0.0022
60.00	-41.943	0.3191	1.430	0.0798
63.00	11.851	0.0435	1.504	0.0086

APPENDIX E.4

THEORETICAL MODEL D

MODEL SPECIFICATION AND CHECKING

VARIABLE (QUANTITATIVE SUMMARY

Iden	Minimum	Mean	Maximum	Val	Miss	
X12A	1.000	2.164	10.000	348	0	Skew
X12B	1.000	1.141	4.000	348	0	Skew
X2	0.00	22.71	100.00	348	0	Skew
PH	0.0	138.7	3154.0	348	0	Skew
PT	2.0	223.8	4783.0	348	0	Skew
X3	1.000	6.822	48.000	348	0	Skew
X6	0.000	2.152	12.000	348	0	Skew
SP	0.00	13.51	100.00	348	0	Skew
X5	0.000	9.095	287.000	348	0	Skew
DQP	0.00	12.06	100.00	348	0	Skew
X7	0.000	6.342	173.000	348	0	Skew

TRANSOFRMING REMAINING VARIABLES X14, X4, X19, X10

```
13  FACTOR [LEVELS=!(1,2)]X14
14  FACTOR [LEVELS=!(1,2)]X4
15  FACTOR [LEVELS=!(1,2)]X19
16  FACTOR [LEVELS=!(0,1)]X10
17  CALCULATE X19=NEWLEVEL(FL;!(1,2,2))
18  & X4=NEWLEVEL(EC;!(1,1,1,1,2,2,2,2,2,2,2,2,2,
    2,2,1,1,\
19  1,1,1,1,1,2,2,2,2,2,2,2,1,1,1,1))
20  & X14=NEWLEVEL(MTT;!(2,2,2,1,2,2,2,2,2,1,1,2,
    2,2,1,1,1,\
21  1,2,1,1,2,1,1,1,2,1,1))
22  & X10=NEWLEVEL(DT;!(0,0,1,1,0))
23  & TT=PT-X5
24  & NT=ROUND(TT/4)
25  & NP=ROUND(PH/4)
```

MODEL SPECIFICATION

***** Regression Analysis *****

```
 Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant, X4, X10, X12A, X12B,
                   X3, X14, X19, X2, X6, X5, X7
```

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	11	514.	46.714
Residual	336	1662.	4.945
Total	347	2175.	6.269
Change	-11	-514.	46.714

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	1.0311	0.0858	12.01
X4 2.00	-0.3186	0.0482	-6.61
X10 1	-0.0728	0.0435	-1.67
X12A	0.0307	0.0121	2.55
X12B	-0.0120	0.0381	-0.32
X3	0.01113	0.00305	3.65
X14 2.00	-0.2292	0.0415	-5.52
X19 2.00	0.4901	0.0407	12.04
X2	-0.003713	0.000847	-4.39
X6	-0.04119	0.00823	-5.00
X5	-0.000311	0.000287	-1.09
X7	-0.004450	0.000516	-8.63

* MESSAGE: s.e.s are based on dispersion parameter with value 1

UNITS WITH HIGH LEVERAGE, RESIDUALS AND COOK'S D

NUMBER	RRAW	LEV	R	COOKD
2.0	19.327	0.18947	-5.208	0.57639
3.0	-14.683	0.01419	-5.178	0.03507
5.0	12.977	0.40909	-4.961	1.54910
6.0	15.681	0.24461	-4.909	0.70942
9.0	-22.099	0.02368	-3.934	0.03412
10.0	-8.461	0.07347	-3.787	0.10336
16.0	-15.701	0.01529	-2.897	0.01184

18.0	11.362	0.16742	-2.725	0.13578
19.0	2.245	0.12286	-2.568	0.08398
21.0	-5.407	0.00515	-2.530	0.00301
22.0	3.962	0.13612	-2.508	0.09007
29.0	10.640	0.02053	-2.216	0.00936
31.0	-26.360	0.31299	-2.164	0.19391
33.0	16.514	0.53842	-2.063	0.45124
34.0	-13.479	0.12967	-2.037	0.05621
35.0	-37.347	0.05055	-1.922	0.01787
45.0	16.496	0.02358	-1.627	0.00581
50.0	-12.248	0.10722	-1.529	0.02551
51.0	18.216	0.04810	-1.508	0.01045
52.0	9.137	0.02033	-1.458	0.00401
58.0	51.508	0.36313	-1.299	0.08746
59.0	0.323	0.53454	-1.298	0.17585
60.0	6.780	0.17127	-1.276	0.03057
63.0	13.057	0.24688	-1.220	0.04438
64.0	17.613	0.06924	-1.217	0.01001
68.0	-25.541	0.28151	-1.141	0.04633
71.0	-19.704	0.01669	-1.110	0.00190
74.0	3.541	0.10847	-1.064	0.01253
83.0	-11.291	0.15120	-0.990	0.01588
97.0	10.468	0.02201	-0.866	0.00153
98.0	-14.345	0.19252	-0.863	0.01615
104.0	23.097	0.10711	-0.742	0.00600
112.0	8.807	0.01587	-0.635	0.00059
127.0	6.968	0.10540	-0.289	0.00089
129.0	-20.275	0.55069	-0.277	0.00854
134.0	-71.462	0.17428	-0.244	0.00114
136.0	-6.953	0.00705	-0.226	0.00003
137.0	-7.182	0.16562	-0.223	0.00090
147.0	17.373	0.13122	-0.150	0.00031
170.0	-10.541	0.03379	0.256	0.00021
175.0	-19.795	0.11340	0.285	0.00094
176.0	-45.412	0.24376	0.293	0.00252
211.0	-34.262	0.09140	0.651	0.00388
233.0	25.765	0.24242	0.804	0.01879
235.0	-18.718	0.04797	0.835	0.00319
240.0	-4.656	0.00349	0.874	0.00024
242.0	26.703	0.06086	0.880	0.00456
273.0	-42.469	0.11690	1.198	0.01727
290.0	24.773	0.14042	1.403	0.02923
297.0	17.424	0.25156	1.436	0.06298
313.0	10.725	0.17324	1.798	0.06160
331.0	8.378	0.14420	2.209	0.07475

APPENDIX E.5
THEORETICAL MODEL E
MODEL CHECKING AND SPECIFICATION
VARIABLE (QUANTITATIVE) SUMMARY

Ident	Minimum	Mean	Maximum	Values	Missing	
NP	0.00	36.71	1012.00	325	0	Skew
NT	1.00	56.81	1835.00	325	0	Skew
X13	0.00	24.29	100.00	325	0	Skew
X7	0.00	12.93	100.00	325	0	Skew
X1	1.000	2.345	10.000	325	0	Skew
X15	1.000	6.972	52.000	325	0	Skew
X8	0.000	2.160	13.000	325	0	Skew
X11	0.000	5.465	32.000	325	0	Skew
X5A	0.00	78.95	1224.00	325	0	Skew
X5B	0.00	50.23	1224.00	325	0	Skew
X5C	0.00	41.95	1224.00	325	0	Skew

TRANSFORMING REMAINING VARIABLES X19, X14

```
   17   FACTOR [LEVELS=!(1,2)]X14
   18   CALCULATE X14=NEWLEVEL(TT;!(2,2,2,1,2,2,2,2,2,1,
        1,2,2,2,\
   19   1,1,1,1,2,1,1,2,1,1,1,2,1,1))
   21   FACTOR [LEVELS=!(1,2)]X4
   22   CALCULATE X4=NEWLEVEL(EC;!(1,1,1,1,2,2,2,2,2,2,
        2,2,2,2,2,\
   23   1,1,1,1,1,1,1,2,2,2,2,2,2,2,1,1,1,1))
   25   FACTOR [LEVELS=!(1,2)]X19
   26   CALCULATE X19=NEWLEVEL(FL;!(1,2,2))
```

MODEL SPECIFICATION

```
***** Regression Analysis *****

 Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant, X19, X14, X4, X13, X7, X1, X15,
                   X8, X11, X5C


*** Summary of analysis ***
    Dispersion parameter is 1

               d.f.      deviance     mean deviance
Regression      10          494.          49.438
Residual       314         1471.           4.686
Total          324         1966.           6.067

Change         -10         -494.          49.438


*** Estimates of regression coefficients ***

                     estimate          s.e.            t
Constant               0.7207        0.0626        11.51
X19 2.00               0.3601        0.0447         8.06
X14 2.00              -0.4535        0.0445       -10.20
X4 2.00               -0.2205        0.0478        -4.62
X13                  0.008061      0.000980         8.23
X7                  -0.003589      0.000600        -5.98
X1                     0.0258        0.0152         1.70
X15                  -0.01535       0.00242        -6.35
X8                   -0.01856       0.00759        -2.44
X11                   0.02347       0.00464         5.06
X5C                -0.0000226     0.0000630        -0.36
* MESSAGE: s.e.s are based on dispersion parameter
  with value 1
```

UNITS WITH HIGH LEVERAGE, RESIDUALS AND COOK'S DISTANCE

NUMBER	RRAW	LEV	R	COOKD
2.0	13.270	0.10180	-4.667	0.24685
3.0	-5.834	0.09556	-4.590	0.22262
5.0	-12.866	0.10120	-4.410	0.21902
7.0	-29.752	0.21987	-3.900	0.42879
10.0	-16.271	0.02462	-3.236	0.02642
16.0	-7.863	0.00686	-2.789	0.00538
23.0	52.388	0.17143	-2.426	0.12176

26.0	25.585	0.05599	-2.321	0.03195
32.0	57.151	0.40799	-2.060	0.29252
33.0	-13.268	0.16637	-2.048	0.08368
35.0	-25.162	0.31118	-2.008	0.18213
36.0	11.588	0.21305	-1.975	0.10561
38.0	9.544	0.21790	-1.907	0.10130
43.0	3.746	0.23248	-1.711	0.08869
50.0	-1.374	0.24155	-1.523	0.07390
51.0	-3.318	0.67646	-1.496	0.46779
55.0	-13.169	0.01823	-1.399	0.00363
57.0	-26.469	0.05651	-1.377	0.01135
63.0	-17.845	0.03011	-1.324	0.00544
76.0	28.192	0.09758	-1.071	0.01240
87.0	-9.938	0.20084	-0.991	0.02468
95.0	13.545	0.03121	-0.940	0.00285
97.0	-16.823	0.14985	-0.935	0.01541
101.0	-6.953	0.00723	-0.881	0.00057
120.0	2.220	0.11754	-0.551	0.00404
125.0	48.462	0.47000	-0.426	0.01612
133.0	-67.562	0.13970	-0.320	0.00166
140.0	14.062	0.12265	-0.194	0.00052
166.0	-13.442	0.01828	0.287	0.00015
170.0	-27.381	0.48682	0.371	0.01303
201.0	-12.857	0.01496	0.647	0.00064
203.0	-20.275	0.04763	0.658	0.00217
220.0	-7.502	0.39744	0.749	0.03700
226.0	-1.783	0.13659	0.788	0.00983
229.0	31.972	0.10854	0.807	0.00792
255.0	-43.216	0.14463	1.038	0.01821
261.0	-13.942	0.02830	1.102	0.00354
285.0	34.630	0.32058	1.381	0.08999
289.0	4.312	0.10036	1.433	0.02292
294.0	5.415	0.12717	1.552	0.03507
313.0	-19.918	0.19883	2.197	0.11983

APPENDIX F.1
THEORETICAL MODEL A
MODEL SELECTION
MAIN EFFECTS

MODELLING OF MAIN EFFECTS VARIABLES
STEP 1:
RESULTS

*** Residual mean deviances ***

6.471	Dropping X17
6.502	Dropping X9
6.508	No change
6.527	Dropping X7
6.534	Dropping X14
6.593	Dropping X16
6.671	Dropping X1
6.701	Dropping X12B
6.903	Dropping X18
8.521	Dropping X5
8.964	Dropping X19

VARIABLES DROPPED - X17

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	9	1601.	177.917
Residual	178	1152.	6.471
Total	187	2753.	14.723
Change	*	0.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.2916	0.0798	-3.65
X18	-0.003024	0.000312	-9.70
X5	0.009820	0.000517	19.00
X16	-0.0668	0.0135	-4.94
X19 2.00	0.9995	0.0480	20.83
X9 1	-0.0795	0.0341	-2.33
X14 2.00	-0.1202	0.0342	-3.51
X12B	-0.1016	0.0159	-6.40
X1	0.02290	0.00383	5.97
X7	-0.002734	0.000864	-3.16

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 2:
RESULTS

*** Residual mean deviances ***

6.466	Dropping X9
6.471	No change
6.491	Dropping X7
6.504	Dropping X14
6.508	Adding X17
6.572	Dropping X16
6.635	Dropping X1
6.664	Dropping X12B
6.982	Dropping X18
8.516	Dropping X5
8.916	Dropping X19

VARIABLE DROPPED - X9, X17

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	8	1596.	199.476
Residual	179	1157.	6.466
Total	187	2753.	14.723
Change	*	5.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.2584	0.0785	-3.29
X18	-0.003094	0.000310	-9.98
X5	0.009645	0.000511	18.88
X16	-0.0681	0.0135	-5.05
X19 2.00	0.9709	0.0464	20.95
X14 2.00	-0.1303	0.0339	-3.84
X12B	-0.1124	0.0152	-7.38
X1	0.02349	0.00383	6.14
X7	-0.002638	0.000864	-3.05

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 3:
RESULTS

*** Residual mean deviances ***

6.466	No change
6.471	Adding X9
6.482	Dropping X7
6.502	Adding X17
6.512	Dropping X14
6.572	Dropping X16
6.639	Dropping X1

6.733	Dropping X12B
7.007	Dropping X18
8.470	Dropping X5
8.922	Dropping X19

VARIABLES DROPPED - X9, X17, X7

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	7	1586.	226.637
Residual	180	1167.	6.482
Total	187	2753.	14.723
Change	*	9.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.2341	0.0781	-3.00
X18	-0.003319	0.000301	-11.02
X5	0.009376	0.000503	18.64
X16	-0.0703	0.0135	-5.22
X19 2.00	0.9590	0.0461	20.78
X14 2.00	-0.1246	0.0339	-3.68
X12B	-0.1077	0.0151	-7.11
X1	0.01957	0.00360	5.43

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 4
RESULTS
*** Residual mean deviances ***

6.466	Adding X7
6.482	No change
6.491	Adding X9
6.517	Adding X17
6.521	Dropping X14
6.597	Dropping X16
6.609	Dropping X1
6.726	Dropping X12B
7.150	Dropping X18
8.423	Dropping X5
8.883	Dropping X19

VARIABLES DROPPED - X9, X17, X7, X14

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	1573.	262.156
Residual	181	1180.	6.521
Total	187	2753.	14.723
Change	*	14.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.3216	0.0743	-4.33
X18	-0.003556	0.000295	-12.05
X5	0.008726	0.000470	18.56
X16	-0.0802	0.0132	-6.07
X19 2.00	0.9867	0.0456	21.66
X12B	-0.0924	0.0146	-6.35
X1	0.02001	0.00360	5.56

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 5
RESULTS

*** Residual mean deviances ***

6.482	Adding X14
6.512	Adding X7
6.518	Adding X9
6.521	No change
6.546	Adding X17
6.654	Dropping X1
6.688	Dropping X16
6.706	Dropping X12
7.327	Dropping X18
8.436	Dropping X5
9.120	Dropping X19

VARIABLES DROPPED - X9, X17, X14, X7

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	1573.	262.156
Residual	181	1180.	6.521
Total	187	2753.	14.723
Change	0	0.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.3216	0.0743	-4.33
X18	-0.003556	0.000295	-12.05
X5	0.008726	0.000470	18.56
X16	-0.0802	0.0132	-6.07
X19 2.00	0.9867	0.0456	21.66
X12B	-0.0924	0.0146	-6.35
X1	0.02001	0.00360	5.56

* MESSAGE: s.e.s are based on dispersion parameter with value 1

MODEL SELECTED BASED ON MODELLING MAIN EFFECTS VARIABLES ONLY

VARIABLES = +X1, +X5, -X12B, -X16, -X18, +X19

MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED MODEL

INITIAL MODEL

```
***** Regression Analysis *****

Response variate: NP
 Binomial totals: NT
    Distribution: Binomial
   Link function: Logit
    Fitted terms: Constant + X18 + X5B + X12B + X1
                  + X19 + X18.X19 + X5B.X19 + X12B.X19
                  + X1.X19


 *** Summary of analysis ***
     Dispersion parameter is 1

                d.f.     deviance     mean deviance
 Regression        9        1640.        182.202
 Residual        178        1113.          6.255
 Total           187        2753.         14.723

 Change           -9       -1640.        182.202

 *** Estimates of regression coefficients ***

                 estimate        s.e.      t
Constant          -0.8046      0.0889   -9.05
X18             -0.003182    0.000292  -10.89
X5B              0.007649    0.000391   19.58
X12B              -0.0988      0.0168   -5.89
X1                0.03220     0.00399    8.07
X19 2.00            1.733       0.124   13.97
X18.X19 2.00     -0.01167     0.00236   -4.95
X5B.X19 2.00     -0.01727     0.00219   -7.89
X12B.X19 2.00      0.0158      0.0326    0.49
X1.X19 2.00      -0.03768     0.00835   -4.51
* MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 1:RESULTS

 * MESSAGE: Term X18 can not be dropped
   because it is marginal to term X18.X19 which
   is in the model

 * MESSAGE: Term X5B can not be dropped
   because it is marginal to term X5B.X19 which
   is in the model

 * MESSAGE: Term X12B can not be dropped
```

```
because it is marginal to term X12B.X19 which
  is in the model

* MESSAGE: Term X1 can not be dropped
  because it is marginal to term X1.X19 which
  is in the model

*** Residual mean deviances ***

       6.221    Dropping X12B.X19
       6.255    No change
       6.333    Dropping X1.X19
       6.357    Dropping X18.X19
       6.565    Dropping X5B.X19
       7.333    Dropping X19

VARIABLES DROPPED - X12B.X19

*** Summary of analysis ***
    Dispersion parameter is 1

                 d.f.      deviance     mean deviance
Regression         8          1640.       204.947
Residual         179          1114.         6.221
Total            187          2753.        14.723

Change             *             0.             *

STEP 2:RESULTS

* MESSAGE: Term X18 can not be dropped
  because it is marginal to term X18.X19 which
  is in the model

* MESSAGE: Term X5B can not be dropped
  because it is marginal to term X5B.X19 which
  is in the model

* MESSAGE: Term X1 can not be dropped
  because it is marginal to term X1.X19 which
  is in the model

*** Residual mean deviances ***

       6.221    No change
       6.255    Adding   X12B.X19
       6.314    Dropping X1.X19
       6.333    Dropping X18.X19
       6.428    Dropping X12B
       6.528    Dropping X5B.X19
       7.531    Dropping X19

VARIABLES DROPPED - X1.X19,X12B.X19
```

```
*** Summary of analysis ***
    Dispersion parameter is 1

             d.f.     deviance    mean deviance
Regression      7        1617.      230.943
Residual      180        1137.        6.314
Total         187        2753.       14.723

Change          *          23.            *


STEP 3:RESULTS

* MESSAGE: Term X18 can not be dropped
  because it is marginal to term X18.X19 which
  is in the model

* MESSAGE: Term X5B can not be dropped
  because it is marginal to term X5B.X19 which
  is in the model

*** Residual mean deviances ***

       6.221    Adding   X1.X19
       6.314    No change
       6.333    Adding   X12B.X19
       6.411    Dropping X18.X19
       6.519    Dropping X12B
       6.536    Dropping X1
       6.637    Dropping X5B.X19
       9.243    Dropping X19

VARIABLES DROPPED - X1.X19,X12B.X19,X18.X19

*** Summary of analysis ***
    Dispersion parameter is 1

             d.f.     deviance    mean deviance
Regression      6        1593.      265.464
Residual      181        1160.        6.411
Total         187        2753.       14.723

Change          *          24.            *


STEP 4:RESULTS

* MESSAGE: Term X5B can not be dropped
  because it is marginal to term X5B.X19 which
  is in the model

*** Residual mean deviances ***
```

```
        6.314    Adding   X18.X19
        6.333    Adding   X1.X19
        6.411    No change
        6.444    Adding   X12B.X19
        6.589    Dropping X12B
        6.620    Dropping X1
        6.786    Dropping X5B.X19
        7.192    Dropping X18
        9.250    Dropping X19
VARIABLES DROPPED - X1.X19,X12B.X19,X18.X19
FINAL MODEL :

Constant + X18 + X5B + X12B + X1 + X19 + X5B.X19


 *** Summary of analysis ***
     Dispersion parameter is 1

                 d.f.     deviance    mean deviance
 Regression        6         1593.      265.464
 Residual        181         1160.        6.411
 Total           187         2753.       14.723

 Change            0            0.            *


 *** Estimates of regression coefficients ***

                    estimate      s.e.       t
Constant             -0.6542     0.0787   -8.32
X18                -0.003415   0.000289  -11.83
X5B                 0.007390   0.000380   19.45
X12B                 -0.0892     0.0143   -6.23
X1                   0.02330    0.00350    6.66
X19 2.00              1.2632     0.0561   22.53
X5B.X19 2.00        -0.01879    0.00217   -8.68
* MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

APPENDIX F.2
THEORETICAL MODEL B
MODEL SELECTION
MAIN EFFECTS

MODELLING OF MAIN EFFECTS VARIABLES

STEP 1: RESULTS

*** Residual mean deviances ***

10.30	Dropping X18
10.45	Dropping X8
10.46	No change
10.46	Dropping X1
10.52	Dropping X7
10.66	Dropping X13
11.28	Dropping X14
22.97	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	1035.9	172.64
Residual	61	628.3	10.30
Total	67	1664.2	24.84
Change	*	0.6	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.3369	0.0497	-6.77
X14 2.00	-0.2922	0.0311	-9.39
X19 2.00	1.0245	0.0366	27.97
X7	-0.000745	0.000160	-4.67
X1	0.004617	0.000737	6.27
X8	-0.01983	0.00585	-3.39
X13	0.03456	0.00593	5.82

STEP 2:RESULTS

*** Residual mean deviances ***

10.30	No change
10.32	Dropping X8
10.46	Adding X18
10.48	Dropping X7
10.68	Dropping X13
10.77	Dropping X1
11.56	Dropping X14
23.22	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	5	1024.4	204.88
Residual	62	639.8	10.32
Total	67	1664.2	24.84
Change	*	11.5	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.4519	0.0365	-12.38
X14 2.00	-0.2976	0.0310	-9.59
X19 2.00	1.0172	0.0366	27.82
X7	-0.000966	0.000146	-6.62
X1	0.004601	0.000737	6.24
X13	0.04080	0.00565	7.22

STEP 3:RESULTS

*** Residual mean deviances ***

10.30	Adding X8
10.32	No change
10.45	Adding X18
10.78	Dropping X1
10.85	Dropping X7
10.99	Dropping X13
11.62	Dropping X14
22.90	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	4	985.3	246.33
Residual	63	678.8	10.78
Total	67	1664.2	24.84
Change	*	39.1	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.4155	0.0359	-11.56
X14 2.00	-0.2258	0.0288	-7.85
X19 2.00	0.9811	0.0360	27.25
X7	-0.000857	0.000145	-5.90
X13	0.05243	0.00532	9.86

STEP 4:RESULTS

Residual mean deviances

10.32	Adding X1
10.41	Adding X18

10.77	Adding X8
10.78	No change
11.15	Dropping X7
11.57	Dropping X14
12.13	Dropping X13
22.60	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	3	950.5	316.84
Residual	64	713.6	11.15
Total	67	1664.2	24.84
Change	*	34.8	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.3731	0.0352	-10.61
X14 2.00	-0.2596	0.0282	-9.20
X19 2.00	0.9468	0.0355	26.67
X13	0.03359	0.00425	7.90

STEP 5 :RESULTS

*** Residual mean deviances ***

10.48	Adding X18
10.78	Adding X7
10.85	Adding X1
10.85	Adding X8
11.15	No change
11.95	Dropping X13
12.28	Dropping X14
22.28	Dropping X19

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	4	1003.9	250.97
Residual	63	660.3	10.48
Total	67	1664.2	24.84
Change	*	-53.4	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.4403	0.0365	-12.07
X14 2.00	-0.2319	0.0285	-8.14

X19 2.00	0.9626	0.0356	27.02
X13	0.05305	0.00503	10.56
X18	-0.0002931	0.0000403	-7.28

STEP 6 : RESULTS

```
*** Residual mean deviances ***
        10.40    Adding   X8
        10.41    Adding   X7
        10.48    No change
        10.65    Adding   X1
        11.15    Dropping X18
        11.36    Dropping X14
        12.07    Dropping X13
        22.12    Dropping X19
```

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	4	1003.9	250.97
Residual	63	660.3	10.48
Total	67	1664.2	24.84
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.4403	0.0365	-12.07
X14 2.00	-0.2319	0.0285	-8.14
X19 2.00	0.9626	0.0356	27.02
X13	0.05305	0.00503	10.56
X18	-0.0002931	0.0000403	-7.28

MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED

```
INITIAL MODEL
 ***** Regression Analysis *****

   Response variate: NP
    Binomial totals: NT
       Distribution: Binomial
      Link function: Logit
       Fitted terms: Constant + X18 + X13 + X14 + X19
                     + X18.X14 + X13.X14 + X18.X19
                     + X13.X19 + X14.X19


 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression       9       1173.9       130.435
 Residual        58        490.2         8.452
 Total           67       1664.2        24.838

 Change          -9      -1173.9       130.435


 *** Estimates of regression coefficients ***

                         estimate      s.e.     t
Constant                  -0.2622    0.0758  -3.46
X18                     -0.001313  0.000138  -9.50
X13                        0.0197    0.0124   1.58
X14 2.00                  -0.2705    0.0879  -3.08
X19 2.00                   1.2614    0.0966  13.06
X18.X14 2.00             0.001107  0.000146   7.59
X13.X14 2.00               0.0189    0.0137   1.38
X18.X19 2.00            -0.001685  0.000758  -2.22
X13.X19 2.00              -0.0563    0.0281  -2.00
X14 2.00 .X19 2.00        -0.4223    0.0815  -5.18
* MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 1: RESULTS

 * MESSAGE: Term X18 can not be dropped
   because it is marginal to term X18.X14 which is in the model

 * MESSAGE: Term X13 can not be dropped
   because it is marginal to term X13.X14 which is in the model

 * MESSAGE: Term X14 can not be dropped
   because it is marginal to term X14.X19 which is in the model
```

```
 * MESSAGE: Term X19 can not be dropped
   because it is marginal to term X14.X19 which is in the model

 *** Residual mean deviances ***

        8.342    Dropping X13.X14
        8.377    Dropping X13.X19
        8.393    Dropping X18.X19
        8.452    No change
        8.765    Dropping X14.X19
        9.328    Dropping X18.X14

VARIABLES DROPPED :X13.X14

 *** Summary of analysis ***
     Dispersion parameter is 1

              d.f.      deviance    mean deviance
 Regression      8        1172.0      146.501
 Residual       59         492.2        8.342
 Total          67        1664.2       24.838

 Change          *           1.9            *

STEP 2:RESULTS

 * MESSAGE: Term X18 can not be dropped
   because it is marginal to term X18.X14 which is in the model

 * MESSAGE: Term X13 can not be dropped
   because it is marginal to term X13.X19 which is in the model

 * MESSAGE: Term X14 can not be dropped
   because it is marginal to term X14.X19 which is in the model

 * MESSAGE: Term X19 can not be dropped
   because it is marginal to term X14.X19 which is in the model

 *** Residual mean deviances ***

        8.277    Dropping X18.X19
        8.296    Dropping X13.X19
        8.342    No change
        8.452    Adding   X13.X14
        9.156    Dropping X14.X19
        9.173    Dropping X18.X14

VARIABLES DROPPED :X13.X14,X18.X19
 *** Summary of analysis ***
     Dispersion parameter is 1

              d.f.      deviance    mean deviance
 Regression      7        1167.5      166.789
```

Residual	60	496.6	8.277
Total	67	1664.2	24.838
Change	*	4.5	*

STEP 3:RESULTS

* MESSAGE: Term X18 can not be dropped
  because it is marginal to term X18.X14 which is in the model

* MESSAGE: Term X13 can not be dropped
  because it is marginal to term X13.X19 which is in the model

* MESSAGE: Term X14 can not be dropped
  because it is marginal to term X14.X19 which is in the model

* MESSAGE: Term X19 can not be dropped
  because it is marginal to term X14.X19 which is in the model

*** Residual mean deviances ***

8.277	No change
8.342	Adding X18.X19
8.393	Adding X13.X14
8.438	Dropping X13.X19
9.151	Dropping X18.X14
9.210	Dropping X14.X19

VARIABLES DROPPED :X13.X14,X18.X19,X13.X19

*** Summary of analysis ***

Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	1149.5	191.576
Residual	61	514.7	8.438
Total	67	1664.2	24.838
Change	*	18.1	*

STEP 4:RESULTS

* MESSAGE: Term X18 can not be dropped
  because it is marginal to term X18.X14 which is in the model

* MESSAGE: Term X14 can not be dropped
  because it is marginal to term X14.X19 which is in the model

* MESSAGE: Term X19 can not be dropped
  because it is marginal to term X14.X19 which is in the model

*** Residual mean deviances ***

8.277	Adding X13.X19

```
        8.296    Adding   X18.X19
        8.438    No change
        8.504    Adding   X13.X14
        8.799    Dropping X13
        9.145    Dropping X14.X19
        9.405    Dropping X18.X14


VARIABLES DROPPED :X13.X14,X18.X19,X13.X19,X13
 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression      5        1118.6      223.722
 Residual       62         545.5        8.799
 Total          67        1664.2       24.838

 Change          *          30.8           *

STEP 5 :RESULTS

 * MESSAGE: Term X18 can not be dropped
   because it is marginal to term X18.X14 which is in the model

 * MESSAGE: Term X14 can not be dropped
   because it is marginal to term X14.X19 which is in the model

 * MESSAGE: Term X19 can not be dropped
   because it is marginal to term X14.X19 which is in the model

 * MESSAGE: Term X13.X14 can not be added
   because term X13 is marginal to it and is not in the model

 * MESSAGE: Term X13.X19 can not be added
   because term X13 is marginal to it and is not in the model

 *** Residual mean deviances ***

        8.438    Adding   X13
        8.758    Adding   X18.X19
        8.799    No change
        9.732    Dropping X14.X19
       10.358    Dropping X18.X14


VARIABLES DROPPED :X13.X14,X18.X19,X13.X19,X13
FINAL MODEL:
Constant + X18 + X14 + X19 +X18.X14 + X14.X19
 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression      5        1118.6      223.722
```

Residual	62	545.5	8.799
Total	67	1664.2	24.838
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-0.1473	0.0297	-4.96
X18	-0.001418	0.000133	-10.64
X14 2.00	-0.1344	0.0387	-3.47
X19 2.00	1.0141	0.0459	22.09
X18.X14 2.00	0.001383	0.000138	10.02
X14 2.00 .X19 2.00	-0.4992	0.0609	-8.20

* MESSAGE: s.e.s are based on dispersion parameter with value 1

APPENDIX F.3
THEORETICAL MODEL C
MODEL SELECTION
MAIN EFFECTS

MODELLING OF MAIN EFFECTS VARIABLES
STEP 1:RESULTS

*** Residual mean deviances ***

6.218	Dropping X4
6.225	Dropping X2
6.237	Dropping X12B
6.245	Dropping X7
6.272	Dropping X5B
6.279	Dropping X12A
6.312	No change
6.327	Dropping X1
6.378	Dropping X6
6.411	Dropping X14
6.543	Dropping X3
7.247	Dropping X10
8.335	Dropping X19

VARIABLES DROPPED X4

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	11	449.1	40.824
Residual	67	416.6	6.218
Total	78	865.7	11.099
Change	*	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6684	0.0731	9.14
X12A	0.0248	0.0122	2.04
X3	-0.01472	0.00309	-4.77
X5B	-0.000208	0.000109	-1.90
X14 2.00	-0.1795	0.0482	-3.73
X19 2.00	0.5401	0.0435	12.41
X10 1	-0.4144	0.0499	-8.31
X7	0.000467	0.000342	1.36
X1	0.0331	0.0118	2.79
X6	0.03261	0.00972	3.36
X2	0.0091	0.0139	0.66
X12B	-0.0336	0.0255	-1.32

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 2: RESULTS
*** Residual mean deviances ***

6.133	Dropping X2
6.152	Dropping X12B
6.154	Dropping X7
6.180	Dropping X5B
6.188	Dropping X12A
6.218	No change
6.242	Dropping X1
6.293	Dropping X6
6.312	Adding X4
6.331	Dropping X14
6.463	Dropping X3
7.148	Dropping X10
8.391	Dropping X19

VARIABLES DROPPED X4, X2

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	10	448.6	44.864
Residual	68	417.1	6.133
Total	78	865.7	11.099
Change	*	0.4	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6705	0.0730	9.18
X12A	0.0241	0.0121	1.99
X3	-0.01325	0.00214	-6.20
X5B	-0.0001616	0.0000831	-1.94
X14 2.00	-0.1793	0.0482	-3.72
X19 2.00	0.5431	0.0433	12.54
X10 1	-0.4205	0.0490	-8.59
X7	0.000595	0.000281	2.12
X1	0.0326	0.0118	2.76
X6	0.02929	0.00830	3.53
X12B	-0.0351	0.0253	-1.39

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 3: RESULTS
*** Residual mean deviances ***

6.072	Dropping X12B
6.099	Dropping X5B
6.102	Dropping X12A

6.110	Dropping X7
6.133	No change
6.155	Dropping X1
6.218	Adding X2
6.225	Adding X4
6.225	Dropping X6
6.245	Dropping X14
6.607	Dropping X3
7.119	Dropping X10
8.329	Dropping X19

VARIABLES DROPPED X4, X2, X12B

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	9	446.7	49.636
Residual	69	419.0	6.072
Total	78	865.7	11.099
Change	*	1.9	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6801	0.0728	9.35
X12A	0.0171	0.0110	1.55
X3	-0.01284	0.00212	-6.07
X5B	-0.0001871	0.0000810	-2.31
X14 2.00	-0.1945	0.0469	-4.15
X19 2.00	0.5419	0.0433	12.52
X10 1	-0.4075	0.0480	-8.49
X7	0.000769	0.000251	3.06
X1	0.0299	0.0117	2.57
X6	0.02402	0.00737	3.26

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 4 : RESUTLTS
*** Residual mean deviances ***

6.020	Dropping X12A
6.062	Dropping X5B
6.072	No change
6.080	Dropping X1
6.119	Dropping X7
6.133	Adding X12B
6.137	Dropping X6
6.152	Adding X2
6.157	Adding X4
6.231	Dropping X14

6.516	Dropping X3
7.018	Dropping X10
8.230	Dropping X19

VARIABLES DROPPED X4, X2, X12B, X12A

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	8	444.3	55.540
Residual	70	421.4	6.020
Total	78	865.7	11.099
Change	*	2.4	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6666	0.0722	9.24
X3	-0.01124	0.00184	-6.10
X5B	-0.0002281	0.0000767	-2.98
X14 2.00	-0.1583	0.0407	-3.89
X19 2.00	0.5406	0.0432	12.51
X10 1	-0.4158	0.0477	-8.71
X7	0.000814	0.000250	3.26
X1	0.03932	0.00996	3.95
X6	0.02255	0.00731	3.09

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 5 :RESULTS

*** Residual mean deviances ***

6.020	No change
6.060	Dropping X5B
6.069	Dropping X6
6.072	Adding X12A
6.085	Dropping X7
6.102	Adding X12B
6.102	Adding X2
6.105	Adding X4
6.149	Dropping X14
6.156	Dropping X1
6.461	Dropping X3
7.007	Dropping X10
8.143	Dropping X19

VARIABLES DROPPED : X4, X2, X12A, X12B, X5B

*** Summary of analysis ***

Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	7	435.4	62.205
Residual	71	430.3	6.060
Total	78	865.7	11.099
Change	*	8.9	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6902	0.0718	9.62
X3	-0.00996	0.00179	-5.57
X14 2.00	-0.1969	0.0386	-5.11
X19 2.00	0.5383	0.0432	12.47
X10 1	-0.3556	0.0431	-8.25
X7	0.000506	0.000227	2.23
X1	0.01939	0.00732	2.65
X6	0.02901	0.00698	4.15

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 6: RESULTS

*** Residual mean deviances ***

6.020	Adding	X5B
6.045	Dropping	X7
6.060	No change	
6.062	Adding	X12A
6.073	Dropping	X1
6.108	Adding	X2
6.137	Adding	X12B
6.146	Adding	X4
6.216	Dropping	X6
6.340	Dropping	X14
6.408	Dropping	X3
6.917	Dropping	X10
8.137	Dropping	X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	6	430.5	71.742
Residual	72	435.2	6.045
Total	78	865.7	11.099
Change	*	5.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.6595	0.0705	9.35
X3	-0.00805	0.00157	-5.12
X14 2.00	-0.1642	0.0356	-4.61
X19 2.00	0.5229	0.0426	12.26
X10 1	-0.3022	0.0359	-8.42
X1	0.01934	0.00732	2.64
X6	0.02511	0.00676	3.71

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 7: RESULTS

*** Residual mean deviances ***

6.045	No change
6.050	Adding X12A
6.058	Dropping X1
6.060	Adding X7
6.085	Adding X5B
6.093	Adding X12B
6.123	Adding X4
6.129	Adding X2
6.152	Dropping X6
6.254	Dropping X14
6.323	Dropping X3
6.932	Dropping X10
8.026	Dropping X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7 , X1

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	5	423.5	84.696
Residual	73	442.2	6.058
Total	78	865.7	11.099
Change	*	7.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.7780	0.0545	14.27
X3	-0.00837	0.00157	-5.33
X14 2.00	-0.1547	0.0355	-4.36
X19 2.00	0.4826	0.0399	12.09
X10 1	-0.2998	0.0359	-8.35
X6	0.02834	0.00665	4.26

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 8 : RESULTS

*** Residual mean deviances ***

5.991	Adding	X12A
6.045	Adding	X1
6.058	No change	
6.073	Adding	X7
6.121	Adding	X4
6.124	Adding	X2
6.141	Adding	X5B
6.142	Adding	X12B
6.222	Dropping	X6
6.234	Dropping	X14
6.362	Dropping	X3
6.918	Dropping	X10
7.974	Dropping	X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7, X1, X6

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	4	405.2	101.312
Residual	74	460.5	6.222
Total	78	865.7	11.099
Change	*	18.2	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.7889	0.0544	14.51
X3	-0.00509	0.00137	-3.73
X14 2.00	-0.1119	0.0340	-3.29
X19 2.00	0.5276	0.0385	13.69
X10 1	-0.2793	0.0355	-7.87

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 9 : RESULTS

*** Residual mean deviances ***

6.058	Adding	X6
6.136	Adding	X12A
6.152	Adding	X1
6.222	No change	
6.256	Adding	X12B

```
        6.280    Adding   X2
        6.284    Dropping X14
        6.292    Adding   X7
        6.301    Adding   X4
        6.303    Adding   X5B
        6.325    Dropping X3
        6.964    Dropping X10
        8.674    Dropping X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7, X1,
X6, X14

 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression      3        394.4       131.458
 Residual       75        471.3         6.284
 Total          78        865.7        11.099

 Change          *         10.9            *


 *** Estimates of regression coefficients ***

                   estimate         s.e.            t
 Constant            0.7137       0.0493        14.48
 X3                -0.00502      0.00137        -3.68
 X19 2.00            0.5534       0.0377        14.69
 X10 1              -0.2990       0.0349        -8.56
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 10: RESULTS
 *** Residual mean deviances ***

        6.222    Adding   X14
        6.234    Adding   X6
        6.262    Adding   X1
        6.284    No change
        6.312    Adding   X2
        6.328    Adding   X5B
        6.334    Adding   X12A
        6.364    Adding   X4
        6.368    Adding   X12B
        6.369    Adding   X7
        6.380    Dropping X3
        7.166    Dropping X10
        9.096    Dropping X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7, X1,
X6, X14, X3
```

Fitted terms: Constant, X19, X10

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	2	380.8	190.415
Residual	76	484.9	6.380
Total	78	865.7	11.099
Change	*	13.5	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5519	0.0219	25.22
X19 2.00	0.6109	0.0343	17.81
X10 1	-0.3452	0.0326	-10.59

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 11 :RESULTS

*** Residual mean deviances ***

6.284	Adding	X3
6.300	Adding	X2
6.325	Adding	X14
6.364	Adding	X1
6.380	No change	
6.434	Adding	X7
6.448	Adding	X5B
6.449	Adding	X6
6.461	Adding	X12A
6.464	Adding	X4
6.465	Adding	X12B
7.754	Dropping	X10
10.562	Dropping	X19

VARIABLES DROPPED X4, X2, X12B, X12A, X5B, X7, X1, X6, X14, X3

Fitted terms: Constant, X19, X10

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	2	380.8	190.415
Residual	76	484.9	6.380
Total	78	865.7	11.099

```
Change              0           0.0            *


*** Estimates of regression coefficients ***

                 estimate        s.e.          t
Constant           0.5519      0.0219      25.22
X19 2.00           0.6109      0.0343      17.81
X10 1             -0.3452      0.0326     -10.59
* MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED INITIAL MODEL

```
 ***** Regression Analysis *****

  Response variate: NP
   Binomial totals: NT
      Distribution: Binomial
     Link function: Logit
      Fitted terms: Constant + X19 + X10 + X19.X10


 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression       3        381.6      127.217
 Residual        75        484.1        6.454
 Total           78        865.7       11.099

 Change          -3       -381.6      127.217

 *** Estimates of regression coefficients ***

                 estimate         s.e.             t
 Constant          0.5590       0.0233         24.01
 X19 2.00          0.5814       0.0472         12.31
 X10 1            -0.3665       0.0402         -9.12
 X19 2.00 .X10 1   0.0621       0.0686          0.91
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 1: RESULTS

 * MESSAGE: Term X19 can not be dropped
   because it is marginal to term X19.X10 which is in the model

 * MESSAGE: Term X10 can not be dropped
   because it is marginal to term X19.X10 which is in the model

 *** Residual mean deviances ***

        6.380    Dropping X19.X10
        6.454    No change


VARIABLES DROPPED X19.X10

 *** Summary of analysis ***
     Dispersion parameter is 1

               d.f.     deviance    mean deviance
 Regression       2        380.8      190.415
 Residual        76        484.9        6.380
```

Total	78	865.7	11.099
Change	*	0.8	*

	estimate	s.e.	t
Constant	0.5519	0.0219	25.22
X19 2.00	0.6109	0.0343	17.81
X10 1	-0.3452	0.0326	-10.59

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 2: RESULTS

*** Residual mean deviances ***

6.380	No change
6.454	Adding X19.X10
7.754	Dropping X10
10.562	Dropping X19

VARIABLES DROPPED X19.X10

*** Summary of analysis ***
*** Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	2	380.8	190.415
Residual	76	484.9	6.380
Total	78	865.7	11.099
Change	0	0.0	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5519	0.0219	25.22
X19 2.00	0.6109	0.0343	17.81
X10 1	-0.3452	0.0326	-10.59

* MESSAGE: s.e.s are based on dispersion parameter with value 1

APPENDIX F.4
THEORETICAL MODEL D
MODEL SELCETION
MAIN EFFECTS

MODELLING OF MAIN EFFECTS VARIABLES
STEP1 :RESULTS

```
 *** Residual mean deviances ***

        4.931    Dropping X12B
        4.934    Dropping X5
        4.939    Dropping X10
        4.945    No change
        4.950    Dropping X12A
        4.970    Dropping X3
        4.987    Dropping X2
        5.005    Dropping X6
        5.021    Dropping X14
        5.062    Dropping X4
        5.151    Dropping X7
        5.363    Dropping X19

VARIABLES DROPPED X12B

 *** Summary of analysis ***
     Dispersion parameter is 1

                d.f.     deviance    mean deviance
 Regression      10         514.         51.376
 Residual       337        1662.          4.931
 Total          347        2175.          6.269

 Change           *           0.              *

 *** Estimates of regression coefficients ***

                    estimate          s.e.            t
 Constant             1.0158        0.0708        14.35
 X4 2.00             -0.3172        0.0480        -6.61
 X10 1               -0.0715        0.0433        -1.65
 X14 2.00            -0.2291        0.0415        -5.52
 X19 2.00             0.4902        0.0407        12.05
 X2                -0.003692      0.000844        -4.38
 X6                 -0.04125       0.00823        -5.01
 X5                -0.000308      0.000287        -1.08
 X3                  0.01130       0.00301         3.76
 X12A                 0.0295        0.0115         2.57
 X7                -0.004448      0.000516        -8.63
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

STEP 2:RESULTS

```
 *** Residual mean deviances ***

        4.920    Dropping X5
        4.924    Dropping X10
        4.931    No change
        4.936    Dropping X12A
        4.945    Adding   X12B
        4.958    Dropping X3
        4.973    Dropping X2
        4.990    Dropping X6
        5.007    Dropping X14
        5.047    Dropping X4
        5.136    Dropping X7
        5.348    Dropping X19
```

VARIABLES DROPPED X12B, X5

```
 *** Summary of analysis ***
     Dispersion parameter is 1

                d.f.      deviance     mean deviance
 Regression        9          513.        56.956
 Residual        338         1663.         4.920
 Total           347         2175.         6.269

 Change            *            1.            *

 *** Estimates of regression coefficients ***

                    estimate          s.e.             t
 Constant             1.0004        0.0692         14.45
 X4 2.00             -0.3188        0.0480         -6.65
 X10 1               -0.0616        0.0423         -1.46
 X14 2.00            -0.2367        0.0409         -5.79
 X19 2.00             0.4963        0.0403         12.32
 X2                -0.003572      0.000836         -4.27
 X6                 -0.03796       0.00764         -4.97
 X3                  0.01082       0.00297          3.64
 X12A                 0.0279        0.0114          2.45
 X7                -0.004561      0.000505         -9.04
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

STEP 3: RESULTS

```
 *** Residual mean deviances ***

        4.911    Dropping X10
        4.920    No change
        4.923    Dropping X12A
        4.931    Adding   X5
        4.934    Adding   X12B
        4.944    Dropping X3
```

4.959	Dropping X2
4.978	Dropping X6
5.004	Dropping X14
5.037	Dropping X4
5.146	Dropping X7
5.356	Dropping X19

VARIABLES DROPPED X12B, X5, X10

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	8	510.	63.811
Residual	339	1665.	4.911
Total	347	2175.	6.269
Change	*	2.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.9940	0.0691	14.38
X4 2.00	-0.3316	0.0472	-7.03
X14 2.00	-0.2432	0.0407	-5.98
X19 2.00	0.4844	0.0395	12.28
X2	-0.003575	0.000835	-4.28
X6	-0.04096	0.00736	-5.56
X3	0.01172	0.00291	4.03
X12A	0.0296	0.0113	2.62
X7	-0.004937	0.000434	-11.38

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 4: RESULTS

*** Residual mean deviances ***

4.911	No change
4.917	Dropping X12A
4.920	Adding X10
4.924	Adding X5
4.926	Adding X12B
4.945	Dropping X3
4.951	Dropping X2
4.988	Dropping X6
5.003	Dropping X14
5.044	Dropping X4
5.276	Dropping X7
5.345	Dropping X19

VARIABLES DROPPED X12B, X10, X5, X12A

```
 *** Summary of analysis ***
     Dispersion parameter is 1

                    d.f.       deviance     mean deviance
 Regression            7           504.       71.948
 Residual            340          1672.        4.917
 Total               347          2175.        6.269

 Change                *             7.            *

 *** Estimates of regression coefficients ***

                        estimate            s.e.             t
 Constant                 1.0535          0.0652         16.16
 X4 2.00                 -0.3389          0.0471         -7.20
 X14 2.00                -0.2103          0.0387         -5.44
 X19 2.00                 0.4585          0.0382         12.01
 X2                    -0.003830        0.000830         -4.62
 X6                     -0.04239         0.00734         -5.77
 X3                      0.01493         0.00263          5.67
 X7                    -0.004888        0.000433        -11.28
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 5: RESULTS

 *** Residual mean deviances ***

        4.911    Adding   X12A
        4.917    No change
        4.923    Adding   X10
        4.930    Adding   X12B
        4.931    Adding   X5
        4.965    Dropping X2
        4.990    Dropping X14
        4.997    Dropping X3
        5.000    Dropping X6
        5.057    Dropping X4
        5.274    Dropping X7
        5.330    Dropping X19

VARIABLES DROPPED X12, X12B, X5, X10

 *** Summary of analysis ***
     Dispersion parameter is 1

                    d.f.       deviance     mean deviance
 Regression            7           504.       71.948
 Residual            340          1672.        4.917
 Total               347          2175.        6.269

 Change                0             0.            *
```

ESTIMATES OF REGRESSION COEFFICIENTS

	estimate	s.e.	t
Constant	1.0535	0.0652	16.16
X4 2.00	-0.3389	0.0471	-7.20
X14 2.00	-0.2103	0.0387	-5.44
X19 2.00	0.4585	0.0382	12.01
X2	-0.003830	0.000830	-4.62
X6	-0.04239	0.00734	-5.77
X3	0.01493	0.00263	5.67
X7	-0.004888	0.000433	-11.28

* MESSAGE: s.e.s are based on dispersion parameter with value 1

MODEL SELECTION - SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED
INITIAL MODEL

```
***** Regression Analysis *****

 Response variate: NP
  Binomial totals: NT
     Distribution: Binomial
    Link function: Logit
     Fitted terms: Constant + X2 + X6 + X3 + X7 + X14
                   + X4 + X19 + X2.X14 + X6.X14 +
                   X3.X14 + X7.X14 + X2.X4 + X6.X4
                   + X3.X4 + X7.X4 + X14.X4 + X2.X19
                   + X6.X19 + X3.X19 + X7.X19 + X14.X19
                   + X4.X19

*** Summary of analysis ***
    Dispersion parameter is 1
```

	d.f.	deviance	mean deviance
Regression	22	692.	31.445
Residual	325	1484.	4.565
Total	347	2175.	6.269
Change	-22	-692.	31.445

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.822	0.153	5.37
X2	-0.01066	0.00285	-3.74
X6	-0.1195	0.0313	-3.82
X3	0.0737	0.0114	6.46
X7	-0.01102	0.00247	-4.45
X14 2.00	-0.169	0.159	-1.06
X4 2.00	-0.311	0.160	-1.95
X19 2.00	0.838	0.169	4.95
X2.X14 2.00	0.00679	0.00225	3.01
X6.X14 2.00	0.0017	0.0202	0.09
X3.X14 2.00	-0.01249	0.00792	-1.58
X7.X14 2.00	-0.00092	0.00136	-0.68
X2.X4 2.00	0.00403	0.00243	1.66
X6.X4 2.00	0.1047	0.0270	3.88
X3.X4 2.00	-0.0552	0.0110	-5.02
X7.X4 2.00	0.00731	0.00230	3.17
X14 2.00 .X4 2.00	0.200	0.171	1.17
X2.X19 2.00	0.00682	0.00202	3.38
X6.X19 2.00	-0.0329	0.0177	-1.85
X3.X19 2.00	-0.02123	0.00677	-3.14
X7.X19 2.00	-0.00228	0.00127	-1.79
X14 2.00 .X19 2.00	-0.6102	0.0951	-6.42

```
 X4 2.00 .X19 2.00      0.195         0.137          1.42
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1

MODELLING AS IN MAIN EFFECTS
AFTER ? STEP THE FINAL RESULT IS

TERM THAT WAS NOT DROPPED        MARGINAL TO
        X2                       X2.X19
        X3                       X3.X4
        X14                      X14.X19
        X19                      X14.X19

TERM THAT WAS NOT ADDED          MARGINAL TO
                                 AND NOT IN MODEL
        X14.X4                   X4
        X4.X19                   X4

 *** Residual mean deviances ***

        4.514    Adding   X6.X4
        4.541    Adding   X7.X4
        4.542    Adding   X2.X14
        4.548    No change
        4.551    Adding   X6.X19
        4.555    Adding   X6.X14
        4.557    Adding   X7.X19
        4.559    Adding   X7.X14
        4.559    Adding   X3.X14
        4.560    Adding   X4
        4.561    Adding   X2.X4
        4.595    Dropping X6
        4.615    Dropping X2.X19
        4.640    Dropping X3.X4
        4.649    Dropping X3.X19
        4.709    Dropping X14.X19
        5.000    Dropping X7


Fitted terms: Constant + X2 + X6 + X3 + X7 + X14 + X19
              + X3.X4 + X2.X19 + X3.X19 + X14.X19

 *** Summary of analysis ***
     Dispersion parameter is 1

              d.f.      deviance     mean deviance
 Regression     10          643.         64.277
 Residual      337         1533.          4.548
 Total         347         2175.          6.269

 Change          0            0.              *
```

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5966	0.0575	10.38
X2	-0.005148	0.000968	-5.32
X6	-0.03404	0.00755	-4.51
X3	0.03279	0.00404	8.12
X7	-0.005632	0.000448	-12.57
X14 2.00	0.0210	0.0481	0.44
X19 2.00	0.8631	0.0988	8.74
X3.X4 2.00	-0.01650	0.00280	-5.89
X2.X19 2.00	0.00811	0.00156	5.19
X3.X19 2.00	-0.02670	0.00432	-6.18
X14 2.00 .X19 2.00	-0.5741	0.0750	-7.66

* MESSAGE: s.e.s are based on dispersion parameter with value 1

APPENDIX F.5
THEORETICAL MODEL E
MODEL SELECTION
MAIN EFFECTS

MODELLING OF MAIN EFFECTS VARIABLES
STEP 1: RESULTS

*** Residual mean deviances ***

4.672	Dropping X5C
4.680	Dropping X1
4.686	No change
4.690	Dropping X8
4.739	Dropping X4
4.753	Dropping X11
4.784	Dropping X7
4.801	Dropping X15
4.878	Dropping X19
4.889	Dropping X13
5.004	Dropping X14

VARIABLES DROPPED X5C

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	9	494.	54.917
Residual	315	1472.	4.672
Total	324	1966.	6.067
Change	*	0.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.7189	0.0624	11.52
X19 2.00	0.3617	0.0445	8.13
X14 2.00	-0.4563	0.0438	-10.42
X4 2.00	-0.2222	0.0475	-4.67
X13	0.008145	0.000952	8.56
X7	-0.003576	0.000599	-5.97
X1	0.0239	0.0142	1.68
X15	-0.01549	0.00239	-6.49
X8	-0.01744	0.00693	-2.52
X11	0.02362	0.00462	5.11

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 2: RESULTS

*** Residual mean deviances ***

4.666	Dropping X1
4.672	No change

4.677	Dropping X8
4.686	Adding X5C
4.726	Dropping X4
4.740	Dropping X11
4.769	Dropping X7
4.792	Dropping X15
4.867	Dropping X19
4.892	Dropping X13
5.003	Dropping X14

VARIABLES DROPPED X5C, X1

*** Summary of analysis ***
Dispersion parameter is 1

	d.f.	deviance	mean deviance
Regression	8	491.	61.430
Residual	316	1474.	4.666
Total	324	1966.	6.067
Change	*	3.	*

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.7485	0.0600	12.48
X19 2.00	0.3685	0.0443	8.31
X14 2.00	-0.4728	0.0427	-11.07
X4 2.00	-0.2115	0.0471	-4.49
X13	0.008582	0.000916	9.37
X7	-0.003278	0.000573	-5.72
X15	-0.01645	0.00232	-7.09
X8	-0.01606	0.00687	-2.34
X11	0.02937	0.00310	9.47

* MESSAGE: s.e.s are based on dispersion parameter with value 1

STEP 3: RESULTS

*** Residual mean deviances ***

4.666	No change
4.668	Dropping X8
4.672	Adding X1
4.680	Adding X5C
4.715	Dropping X4
4.754	Dropping X7
4.812	Dropping X15
4.870	Dropping X19
4.932	Dropping X13
4.937	Dropping X11
5.040	Dropping X14

VARIABLES DROPPED X5C, X1, X8

```
*** Summary of analysis ***
    Dispersion parameter is 1

                d.f.     deviance     mean deviance
Regression        7          486.         69.427
Residual        317         1480.          4.668
Total           324         1966.          6.067

Change            *            5.              *


*** Estimates of regression coefficients ***

                    estimate          s.e.           t
Constant              0.7212        0.0588       12.26
X19 2.00              0.3293        0.0410        8.03
X14 2.00             -0.4817        0.0426      -11.31
X4 2.00              -0.1879        0.0460       -4.09
X13                 0.008978      0.000902        9.96
X7                 -0.003637      0.000551       -6.60
X15                 -0.01865       0.00213       -8.77
X11                  0.02921       0.00311        9.40
* MESSAGE: s.e.s are based on dispersion parameter with value 1
```

STEP 4: RESULTS

```
*** Residual mean deviances ***

       4.666    Adding   X8
       4.668    No change
       4.677    Adding   X1
       4.679    Adding   X5C
       4.706    Dropping X4
       4.791    Dropping X7
       4.857    Dropping X19
       4.899    Dropping X15
       4.935    Dropping X11
       4.970    Dropping X13
       5.059    Dropping X14
```

VARIABLES DROPPED X5C, X1, X8, X4

```
*** Summary of analysis ***
    Dispersion parameter is 1

                d.f.     deviance     mean deviance
Regression        6          469.         78.201
Residual        318         1497.          4.706
Total           324         1966.          6.067

Change            *           17.              *

*** Estimates of regression coefficients ***

                    estimate          s.e.           t
```

```
 Constant               0.6162         0.0527           11.68
 X19 2.00               0.2906         0.0399            7.29
 X14 2.00              -0.4340         0.0409          -10.61
 X13                  0.008895       0.000899            9.90
 X7                  -0.004022       0.000542           -7.42
 X15                  -0.01918        0.00212           -9.05
 X11                   0.02654        0.00304            8.73
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1

STEP 5: RESULTS

 *** Residual mean deviances ***

        4.668    Adding   X4
        4.706    No change
        4.715    Adding   X8
        4.718    Adding   X1
        4.721    Adding   X5C
        4.858    Dropping X19
        4.865    Dropping X7
        4.934    Dropping X11
        4.952    Dropping X15
        5.003    Dropping X13
        5.046    Dropping X14

VARIABLES DROPPED X5C, X1, X8, X4,
 ***** Regression Analysis *****

  Response variate: NP
   Binomial totals: NT
      Distribution: Binomial
     Link function: Logit
      Fitted terms: Constant, X19, X14, X13, X7, X15, X11


 *** Summary of analysis ***
     Dispersion parameter is 1

              d.f.     deviance    mean deviance
 Regression      6         469.        78.201
 Residual      318        1497.         4.706
 Total         324        1966.         6.067

 Change          0           0.             *

 *** Estimates of regression coefficients ***

                    estimate             s.e.               t
 Constant             0.6162           0.0527           11.68
 X19 2.00             0.2906           0.0399            7.29
 X14 2.00            -0.4340           0.0409          -10.61
 X13                0.008895         0.000899            9.90
 X7                -0.004022         0.000542           -7.42
 X15                -0.01918          0.00212           -9.05
 X11                 0.02654          0.00304            8.73
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1
```

MODEL SELECTION -SIGNIFICANT MAIN EFFECTS VARIABLES WITH 2 FACTOR INTERACTION INCLUDED
INITIAL MODEL

```
***** Regression Analysis *****

  Response variate: NP
   Binomial totals: NT
      Distribution: Binomial
     Link function: Logit
      Fitted terms: Constant + X13 + X7 + X15 + X11 + X14
                    + X19 + X13.X14 + X7.X14 + X15.X14
                    + X11.X14 + X13.X19 + X7.X19
                    + X15.X19 + X11.X19 + X14.X19

 *** Summary of analysis ***
    Dispersion parameter is 1
```

	d.f.	deviance	mean deviance
Regression	15	544.	36.284
Residual	309	1422.	4.600
Total	324	1966.	6.067
Change	-15	-544.	36.284

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	0.5144	0.0942	5.46
X13	0.00246	0.00189	1.30
X7	-0.00503	0.00143	-3.52
X15	0.00109	0.00382	0.28
X11	0.03528	0.00879	4.01
X14 2.00	-0.319	0.112	-2.86
X19 2.00	0.638	0.131	4.88
X13.X14 2.00	0.01075	0.00192	5.61
X7.X14 2.00	0.00002	0.00129	0.02
X15.X14 2.00	-0.02636	0.00456	-5.78
X11.X14 2.00	-0.00791	0.00959	-0.82
X13.X19 2.00	0.00172	0.00208	0.83
X7.X19 2.00	0.00341	0.00142	2.41
X15.X19 2.00	-0.01754	0.00535	-3.28
X11.X19 2.00	0.01426	0.00809	1.76
X14 2.00 .X19 2.00	-0.523	0.101	-5.16

* MESSAGE: s.e.s are based on dispersion parameter with value 1

MODELLING AS IN MAIN EFFECTS
AFTER 7 STEP THE FINAL RESULT IS

TERM THAT WAS NOT DROPPED	MARGINAL TO
X13	X13.X14
X15	X15.X14
X14	X14.X19
X19	X14.X19

```
TERM THAT WAS NOT ADDED        MARGINAL TO AND NOT
                               IN THE MODEL

 X13.X14.X19                    X13.X19
 X7.X14.X19                     X7.X14
 X15.X14.X19                    X15.X19
 X11.X14.X19                    X11.X14

 *** Residual mean deviances ***

        4.561    Adding   X15.X19
        4.569    No change
        4.574    Adding   X7.X14
        4.577    Adding   X13.X19
        4.582    Adding   X11.X19
        4.582    Adding   X7.X19
        4.583    Adding   X11.X14
        4.644    Dropping X7
        4.667    Dropping X14.X19
        4.681    Dropping X15.X14
        4.682    Dropping X13.X14
        4.836    Dropping X11

VARIABLES DROPPED X11.X14, X7.X19, X11.X19, X13.X19, X7.X14,
                  X15.X19

Fitted terms: Constant + X13 + X7 + X15 + X11 + X14
+ X19 + X13.X14 + X15.X14 + X14.X19

 *** Summary of analysis ***
     Dispersion parameter is 1

                d.f.      deviance     mean deviance
 Regression        9          527.        58.517
 Residual        315         1439.         4.569
 Total           324         1966.         6.067

 Change            0            0.             *

                         estimate         s.e.            t
 Constant                  0.5697       0.0757         7.53
 X13                      0.00186      0.00138         1.34
 X7                     -0.003033     0.000568        -5.34
 X15                     -0.00408      0.00322        -1.27
 X11                      0.03100      0.00332         9.35
 X14 2.00                 -0.3736       0.0870        -4.29
 X19 2.00                  0.5985       0.0628         9.54
 X13.X14 2.00             0.01070      0.00168         6.36
 X15.X14 2.00            -0.02509      0.00395        -6.35
 X14 2.00 .X19 2.00       -0.4827       0.0809        -5.97
 * MESSAGE: s.e.s are based on dispersion parameter
with value 1
```